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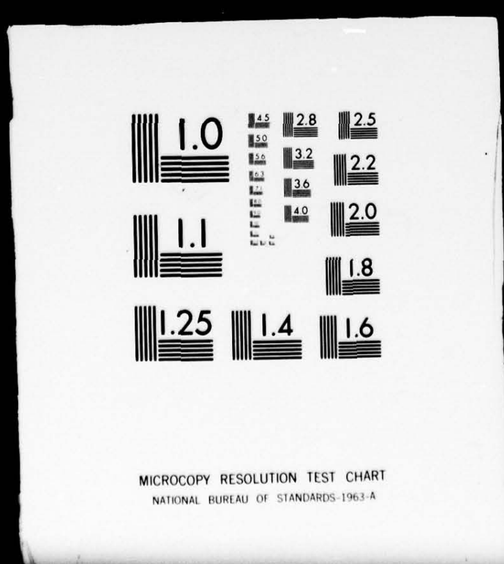

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The second section of the report deals primarily with the sources and inputs of the two nutrients, phosphorus and nitrogen, to Lake Erie. There is little specific information on those inputs, and, therefore, information has been assembled from other locations on the sources of these nutrients. The historical growth in population in the Lake Erie Basin has also been traced.

The discussion of the sources of phosphorus into surface waters surveys the field work which has been carried out on this topic. Also discussed is the effectiveness of the Erie County detergent phosphate ban, a unique nonstructural action taken to manage nutrient enrichment of surface waters.

The subsection on historical trends in population lists the total population for the U. S. and Canadian portions of the basin and the urban population growth in the U. S. portion.

In the subsequent analysis of historical trends in agriculture, major crops, and animal populations have been inventoried and trends in fertilizer use studied.

Finally, trends in detergent use are identified and consumption determined by type of detergent.

HISTORICAL TRENDS IN POLLUTANT LOADINGS TO LAKE ERIE

Final Project Report
Civil Engineering Department
State University of New York at Buffalo

Robert P. Apmann
Principal Investigator

November 1975

Lake Erie Wastewater Management Study
U.S. Army Corps of Engineers
1776 Niagara Street
Buffalo, NY 14207

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PREFACE

This work was authorized by contract DACW 49-75-C-0045 as part of the Lake Erie Wastewater Management Study, U.S. Army Corps of Engineers, Buffalo District. The contract was to develop the historical loadings of pollutants and water quality trends for Lake Erie. The development of this information will facilitate correlating loading trends with water quality trends and the development of material balances for certain material inputs for the Lake Erie waterbody and its tributary basins. Finally, the development of this information will assist in the evaluation of the reduction of pollutant loadings on the quality of the Lake Erie waterbody.

The research on historical trends in pollutant loadings to Lake Erie was performed at the Civil Engineering Department of the State University of New York at Buffalo during the period January 1, 1975 to November 1, 1975. Dr. Robert P. Apmann was the Principal Investigator and carried out the work represented by section 1, "Sediment and Water Yields in the Lake Erie Basin." He was assisted in the trend analyses of sediment yield by Dr. John Huddleston. Mr. David Edson carried out the analyses which are reported in section 2, "Cultural Trends in the Lake Erie Basin". He was assisted in computational work by Mr. Andrew Kwong.

ABSTRACT

A study of the sediment and water yields of the Lake Erie Basin has been undertaken. Based on over 20 years of daily monitoring of the suspended sediment yield with time could be discovered. However, cores taken from the bed of Lake Erie demonstrate that the sedimentation rates since 1935 are up to 3 times greater than in the period 1850-1935. In turn the average sedimentation rate for the entire postglacial period has been approximately 1/7 of its present rate.

Three distinct periods of sediment production seem to be indicated: the pre-colonial, in which sediment yields were typical of a forested watershed; the "early colonial" from approximately 1850-1935, which includes the era of rapid deforestation of the entire watershed; and the modern period of high sediment yields from urbanization and severe shoreline erosion.

The deforestation carried out by the colonists was probably the major physical impact suffered by the basin and the lake. Sediment yields were dramatically increased leading to significant changes in the lake and its biota. The substantially higher sedimentation rates of recent times have been discovered only through analysis of cores from the lake bottom, but a study of the sediment budget of the lake indicates that shoreline erosion alone could produce almost all of the fine-grained sediments which are deposited in the lake bed. River inputs are a comparatively minor source.

The suspended sediment load delivered from the watershed by its tributaries is 4,570,000 tons/year, with 97% confidence limits of

4,060,000 and 4,930,000. The Detroit River adds another 1,570,000, but outflow from the Niagara River is about 4,500,000 tons/year. Other sources of fine-grained sediments are shoreline erosion at 28 million tons/year and miscellaneous sources which possibly add 2,000,000 tons/year. About 3.5 million tons of material is dredged from the lake annually and with present practices it is disposed of outside the lake. The measured annual sediment deposition in the lake is 30 million tons/year.

The tributary river inflows add another 2,500,000 tons of bed load, or coarse-grained material, to the lake annually. This figure was derived from reservoir data and the confidence limits are extremely wide.

Sediment yields and erosion rates vary widely from year to year and from place to place. One of the characteristics of the data is its large variability, the standard deviation of the annual series being as large as 60% of the mean values. Deposition rates in the lake are equally variable, responding to lake levels and subsequent shoreline erosion. About 58% of the fine-grained sediments are deposited in the Eastern Basin, 30% in the Central and 12% in the Western. The deposition rate is the highest in the Eastern Basin and the sedimentation rates in Lake Erie are the highest of all the Great Lakes.

The natural and cultural loadings of certain contaminants have been calculated from sediment cores. Although the use of nitrogen fertilizers predominates in the Central and Western Basins of the watershed, deposition of nitrogen is largest in the Eastern Basin of the lake. In fact, the Eastern Basin is the sink for more than half of the contaminant mass.

A comparison of anthropogenic to natural loadings to the lake shows 3.5 times as much lead being deposited from cultural as from natural sources; 2.3 times as much chromium; 2.1 times as much mercury, zinc, and cadmium; and twice as much nitrogen. Nickel, copper, and phosphorous are supplied from natural sources at a slightly higher rate than from cultural sources. About 1.6 times as much organic carbon comes from natural as from cultural sources. The phosphorous breakdown is doubtful.

From the 1970-71 lake bottom cores it was calculated that about 130,000 tons/year of nitrogen was being retained in the lake (119,600 metric tons/year).

Trends in precipitation of Lake Erie between 1860 and 1958 were studied. Over that period the statistical analysis showed that the precipitation regime had not changed. Neither were any time trends discovered in the water runoff of the Auglaize River at Defiance, Ohio for the period 1915-1973. The land use of this major watershed has been agriculturally oriented throughout the period. On the other hand, a study of the Cuyahoga River seems to show about a 0.7% increase in runoff coefficient over the past 70 years. This result is not certain because the old records of water runoff are sparse.

Lake levels back to 1800 have been plotted, showing the present high levels not to have been exceeded in historic times. However, levels nearly as high were reported in 1858 and 1838, and possibly the lowest historic levels in the period 1800-1810. The period 1830-1880 was a half century of comparatively high levels and precipitation at Cincinnati, Ohio, between 1835 and 1855 was well above average.

Total surface runoff into Lake Erie was calculated at 20,451 cfs

for the period 1950-1972. For the 10 years, 1963-1972, it was found to have decreased to 18,908 cfs. These neglect the inflow of the Detroit River, approximately 176,000 cfs.

In the U.S. portion of the Lake Erie watershed the Western Basin has the greatest potential for contaminant yield of the three sub-basins. In the analysis only the magnitudes of domestic and agricultural wastes were considered. Industrial contributions were not analyzed. However, the major urban centers of the Western Basin undoubtedly are principal contributors of those types of wastes.

Of the three sub-basins, the Western is far by the most substantial. The past trends in agricultural production support the view that it will continue to be dominant. In addition, the Western Basin supports the largest urban population of the three and its population growth rate is also the fastest.

Although the Central and Eastern Basins have shown slight declines in importance as agricultural producing areas, they have demonstrated increases in urban population growth. A moderate growth in soybean production and beef cattle population has also been manifested in the Central Basin.

The Eastern Basin is the smallest pollutant producing area. The urban population is relatively small and agricultural production has tended to drop.

Analysis of a limited amount of Canadian data led to the conclusion that fertilizer use in that country is similar to that in the U.S. The phosphorous content in Canadian fertilizers tends to be less than in the U.S.

Consideration of fertilizer data shows that phosphorous content has at least temporarily leveled off at about 6.5%. The inclusion of newer superphosphates may tend to drive this proportion up to a new limit near 20%. The noticeable trend in fertilizer usage has been a spectacular shift in nitrogen content. The use of nitrogen in solution and anhydrous ammonia, which began seriously in 1960, has driven the overall proportion of nitrogen in fertilizers to 16%, and there is every reason to believe that the percentage will continue to rise.

The rate of increase in nitrogen applied to agricultural land in the Western Basin has been approximately 9% compounded annually. This is almost equal to the rate of increase in nitrate concentration in the Maumee River at Waterville and suggests, although it is impossible to prove , that the dramatic rise in nitrates is the effect of the much greater use of nitrogen fertilizers. Since the Public Health Service recommends a limit of 45 mg/ℓ for nitrate concentration in potable drinking water, and since concentrations in the Maumee River are reguarly above 30, this situation warrants attention and considerable study. If it is found that nitrogen in fertilizers is indeed leading to substantial increases in nitrates in surface water, the management of that problem will be very difficult.

A study of detergent use in the U.S. shows a steady increase in use over the past 20 some years. The major trend has been the substitution of synthetic detergents for traditional soap products. At one time soap was the primary detergent in use. At present, soap holds approximately 16% of the market, with synthetic detergents being very widely used for cleaning purposes.

INTRODUCTION

This paper investigates historical trends in pollutant loadings to Lake Erie. The first of two sections of this report analyzes information on the amount of sediments delivered to Lake Erie and discusses historical trends in sediment yield. There are two primary sources of data: (1) measurements of suspended sediment load made in some of the tributary rivers and (2) analyses of shoreline erosion and sedimentation rates in Lake Erie. The important aspects of suspended load measurements are discussed first, followed by the shoreline erosion and sedimentation rates. These lead to a subsequent analysis of the sediment budget.

Since the loading of contaminants to the lake is manifested by sedimentation, results are presented of analyses of contamination inputs from bottom coring. Trends in precipitation, runoff, and lake levels have been analyzed and are presented followed by the calculation and tabulation of the average surface water runoff to Lake Erie.

The second section of the report deals primarily with the sources and inputs of the two nutrients, phosphorous and nitrogen, to Lake Erie. There is little specific information on those inputs, and therefore information has been assembled from other locations on the sources of these nutrients. The historical growth in population in the Lake Erie Basin has also been traced.

Initially, the discussion of the sources of phosphorus into surface waters surveys the fieldwork which has been carried out on this topic. It does not attempt to explain or list the mechanisms by which phosphorus is transported in the physical environment, but represents

a search of published literature. All results are credited in the bibliography. Also discussed is the effectiveness of the Erie County detergent phosphate ban, a unique non-structural action taken to manage nutrient enrichment of surface waters.

The sub-section on historical trends in population lists the total population for the U.S. and Canadian portions of the basin and the urban population growth in the U.S. portion. This will be of value in determining the future magnitude of the urban waste contributions to Lake Erie.

In the subsequent analysis of historical trends in agriculture, major crops and animal populations have been inventoried and trends in fertilizer use studied. The land area used for this analysis excludes the drainage basins of Lake St. Clair and the Detroit River. From this study a particularly rapid increase in the use of nitrogen for fertilization has been detected, which may play a key role in management of the lake's water quality.

Finally, trends in detergent use are identified and consumption determined by type of detergent. The development of this subsection was hindered by the refusal of manufacturers to divulge sales figures. However, Federal Commerce Department publications were analyzed to determine realistic figures on detergent use for the Lake Erie basin.

SEDIMENT AND WATER YIELDS IN THE LAKE ERIE BASIN

In July 1944 Paul B. Sears, then Professor of Botany at Oberlin College, wrote that the substantial soil erosion from the rich agricultural watersheds of the Maumee, Toussaint, Portage, and Sandusky Rivers was responsible for the loss of production of whitefish, herring, and sturgeon in the Lake Erie fisheries. Catches of these fish had dropped by about 90% (1). The inwash of silts to the western basin had gradually covered the clean bottoms which are needed by those species for spawning.

Moreover, three years earlier, Thomas Langlois had reported:

> "The specific factor that may be held responsible for changing Lake Erie from a suitable place for the cisco whitefish and perch is the increased turbidity of the waters in the western part of the lake....From an airplane I have seen the brownish streak of Portage River water reaching from Port Clinton at least 5 miles into the lake to a point north of Green Island...."(2)

Langlois thus countered the claims of some wildlife biologists that the decline in the catch of comercial species in the lake and the changing composition of fishes in the catch were caused by overly intensive fishing operations. The evidence appeared clear: agricultural development had increased the inflowing sediment loads, destroying the spawning areas and eliminating important vegetational areas which were essential to the fish.

Silt pollution had destroyed the lotus beds at Monroe, Michigan; the dense aquatic meadows of Sandusky Bay were gone; and the leafy aquatic plants which had been present in the Maumee Bay even in 1905 had disappeared by 1941.

The period of intensive, large-scale agricultural development which led to this significant change in regime began about 1850 (3). Prior to

this the Lake Erie Basin was largely forested. The modern forest composition was established in the Great Lakes region about 4000 years ago, and the first evidence of agriculture in New York dates back 1000 years. The adoption of an agricultural economy and increasing cultural diffusion from the Ohio Valley and Middle Atlantic States aided in the development of the Iroquois tribes. By the arrival of the French in the late 16th century a well-developed system of trade, barter, and cultural contact existed (4).

The Iroquois had little impact on the land, compared to the colonial settler. Excavations at the Riverhaven No. 2 site on Grand Island, New York, show that the mammals of the deciduous forest of 2700 years ago could have supported a population of between 13 and 26 humans per 10 square miles. The actual population has been estimated at about 2 per 10 square miles (5). In contrast, the 1900 population density of the Lake Erie Basin was 1380 persons per 10 square miles, and in 1970, was another 3.70 times greater. Both in numbers and technological effectiveness the colonists were far more capable than the indigenous population in altering the shape of the land.

To support larger populations it was necessary to derive more calories from the land. The vast deciduous hardwood forests of the basin were cut down by 1890, being replaced by the highly productive farms that mark intensive American agriculture. One of the byproducts of this spectacular and sudden change in land use was the greatly increased soil loss which, as both Sears and Langlois noted, altered the composition of the Lake Erie fauna.

It is believed that a second major pattern of land use change has

recently triggered additional soil loss and added to the material flowing into the lake. This is associated with the trend towards urbanization which began after the Second World War. From the available data it has proved impossible to verify any recent suspected increases in soil loss. All of the stations where sediment load is measured are located upstream from the major urban centers in the Lake Erie Basin, apart from Akron, Ohio, which lies partly within the Cuyahoga River Basin.

Let us note, however, that the sediments which enter the lake are not only derived from agricultural watershed erosion, but also from the eroding shorelines of the lake itself. Furthermore, the impacts of sediments as contaminants go beyond the suppression of the habitats for desirable fish species since some chemical contaminants are also strongly associated with inflowing sediment loads. An example is the close relationship between inflowing phosphorus and suspended sediment.

Suspended Sediment Measurements

Suspended sediment measurements have been taken for varying periods at several locations in the Lake Erie Basin by USGS, ARS, and WSC. The Maumee and Cuyahoga Rivers have been monitored since 1950 and daily sediment loads and water discharges for a number of other streams exist for shorter time periods. A summary of this information appears in Table 1.1. In Ohio there appears to be enough monitored watersheds to allow a regional analysis of suspended sediment yields. Because the water yield increases in an orderly manner around the basin it seems likely that trends in sediment yield will follow a similar pattern.

The measured discharge of suspended sediment at a river cross-section is not the total transport of sediment past that gaging point, since the samples which are used are not capable of measuring the sediment which is carried in the thin 3" region above the stream bed. The material flowing in that zone has a relatively low velocity and is composed of the coarsest fractions of the sediment. Studies on a number of rivers have shown that this unmeasured load may not be significant. Without more detailed knowledge about the actual characteristics of the particular streams which flow into Lake Erie an estimate of the significance of the unmeasured load cannot be accurately made. Instead, it will be assumed that some relationship has existed between unmeasured load and suspended load in each stream, and that regardless of the magnitude of the unmeasured load, the suspended sediment load can be analyzed and correlated with certain independent variables to yield significant information about its particular delivery characteristics.

Table 1.1 SUSPENDED SEDIMENT MEASUREMENT STATIONS IN LAKE ERIE BASIN

(a) U.S. Geological Survey

Station Number	Station, Location	Area, Sq.Miles	Yield CFS/Sq.Mi.	Comments
04176500	River Raisin near Monroe	1042	0.654	Daily Sediment, 1966-present
	Saline River	95	0.64	(Yield tabulated for comparison)
	River Raisin at Tecumseh	267	0.63	(Yield tabulated for comparison)
	River Raisin at Adrian	463	0.64	(Yield tabulated for comparison)
04185000	Tiffin River at Stryker	441	0.685	Partial measurements, 1970-present
04186500	Auglaize, Fort Jenning	332	0.855	Partial measurements, 1970-present
04189000	Blanchard at Findlay	346	0.676	Partial measurements, 1970-present
04191500	Auglaize at Defiance	2318	0.711	Partial measurements, 1970-present
04193500	Maumee at Waterville	6314	0.734	Daily Sediment, 1950-present
	Portage at Woodville	433	0.684	Daily Sediment, 1950-1956
04196800	Tymochtee Ck, at Crawford	229		Partial measurements, 1970-present
04196000	Sandusky, Bucyrus	89.8	0.908	Partial measurements, 1970-present
04196500	Sandusky, Upper Sandusky	298	0.788	Partial measurements, 1970-present
04197000	Sandusky, Mexico	776	0.710	Partial measurements, 1970-present
	Sandusky, Fremont	1248	0.726	Daily Sediment, 1950-1956
04199000	Huron, Milan	363	0.749	Partial measurements, 1970-present
04199500	Vermilion near Vermilion	262	0.847	Partial measurements, 1970-present
04200500	Black at Elyria	392	0.786	Partial measurements, 1970-present
04201500	Rocky River at Beria	267	0.944	Partial measurements, 1969-present
04206000	Cuyahoga at Old Portage	404	1.01	Daily Sediment, March 1972-present
	Cuyahoga at Independence	709	1.06	Daily Sediment, 1950-present
04209000	Chagrin at Willoughby	246	1.28	Partial measurements, 1969-present
04212000	Grand River, Madison	587	1.10	Partial measurements, 1970-present
04212500	Ashtabula at Ashtabula	118	1.25	Partial measurements, 1970-present
04213000	Conneaut at Conneaut	178	1.35	Partial measurements, 1970-present

Table 1.1 (Continued)

(b.) Agricultural Research Service

Station Number	Station, Location	Area, Sq.Miles	Yield CFS/Sq.Mi.	Comments
04213500	Cattaraugus Ck. at Gowanda	432	1.65	(Yield tabulated for comparison)
04215500	Cazenovia Ck. at Ebenezer	134	1.64	Flood water sampling only
04214500	Buffalo Ck. at Gardenville	144	1.31	Flood water sampling only
04215000	Cayuga Ck. at Lancaster	95	1.26	Flood water sampling only

(c.) Water Survey of Canada

Station Number	Station, Location	Area, Sq.Miles	Yield CFS/Sq.Mi.	Comments
02GC007	Big Creek nr Walsingham	228	0.912	Daily Sediment,1967-present
2GC004	Big Otter Creek nr. Vienna	269	1.05	Daily Sediment,1967-present
2GH001	Sturgeon Cr. nr. Leamington	4.9	0.991	Daily Sediment, 1971

The suspended sediment discharge does not reflect the transporting capacity of the stream channel at the gaging station but rather the delivery characteristics of the watershed. During the very largest flood flows the stream channel will erode and add some material to the load in suspension, but most of the time the suspended load reflects the complicated processes of erosion, deposition, and transportation in the watershed and not the channel which is only a vehicle. The quantity of suspended load cannot be easily correlated with the hydraulic and geometric characteristics of the stream flow, since in most instances the water has much more capacity for transport of fine material than can be satisfied by the sediment being delivered to it.

The concept of "wash load" has been used to differentiate that fraction of the total load which is derived from watershed erosion, in contrast to channel erosion. The particles which make up the wash load include those of colloidal size, which can be transported by rivers in enormous concentrations. Since a very large fraction of the suspended sediment originates from watershed erosion we conclude that to develop a method for calculating the suspended sediment yield required an analysis of those watershed and hydrologic variables which influence wash load delivery rather than an analysis of the transport characteristics of the stream channels.

As further evidence that the suspended load is derived from soil erosion, a look at the particle-size analyses of suspended sediment samples failed to yield any evident correlation between discharge and percentage of clay in the sample. In the samples which have been analyzed in the native river water the particles smaller than about 0.01 mm tended to agglomerate into

larger flocs, probably due to the chemical characteristics of the water. When the samples are dispersed by chemical and mechanical techniques and analyzed in distilled water, the results are completely different. In samples taken from the Maumee River from 50 to 80% of a sample turns out to be composed of particles smaller than 0.002 mm, sizes which lie in the clay range. For the water discharges exceeding 7,000 cfs, which were the only ones sampled, there has been no evident trend of clay content with discharge.

Frequency Characteristics of Suspended Load

An analysis of 19 years of record on the Cuyahoga River between 1950 and 1970 developed relationships between frequency of occurrence and the amount of load delivered (6). It was discovered that on the average, the load delivered during the maximum day of the year made up 14% of the total annual load. Half of the total annual load is delivered on only eight days of the year and the subsequent nine days, *in terms of rank, add an additional* 17% of the total load. In terms of discharge, it can be stated that the eight days in which load equals and exceeds 6,000 tons/day contribute 50% of the load and the 17 days on which load equals or exceeds 3,000 tons/day contribute 67% of the load. Since the average daily load for that period was 592 tons/day, the statistics can be interpreted in another way; that the days on which the load exceeds five and ten times the daily average contribute 50 and 67% of the load, respectively. The process of suspended sediment delivery is therefore one in which the few extreme events contribute the most substantial mass of contaminants.

Watershed Erosion

The soil erosion process in a watershed is activated both by raindrop

impact and by runoff, with the amount of material transported depending on both the availability of material and the transportation capacity of the erosive agents (7). The detachment of soil by rainfall seems to be nearly proportional to the product of EI, the rainfall kinetic energy and the maximum 30 minute intensity. Soil loss also depends on the area of the increment, the soil type, and the vegetative cover. Erosion by runoff is largely influenced by the hydraulic roughness of the surface, the discharge rate of the runoff and the slope of the surface.

The capacity of the rainfall to carry away eroded soil depends also on the surface slope, the amount of rain, soil type, topography, and the wind velocity. Finally, the capacity of the runoff to transport the eroded sediment is primarily dependent on discharge and slope for a given soil particle size and density.

The quantity of load delivered depends on the relation between detachment and capacity. Regardless of capacity, if the amount detached is smaller, the delivery will be limited by detachment. If capacity is less than detachment, the former is the limiting factor.

Ellison found the duration of rainfall to be another important factor in raindrop erosion, for in his experiments the erosion rate decreased as the rainfall continued, apparently due to the increasing unavailability of erodible material (8).

Many of the variables which are important in sediment delivery also motivate the delivery of runoff from a watershed. The quantity of

runoff is higher for the more intense rainfall rates, as is the raindrop erosion affect. The discharge of runoff, for a given amount of rainfall, will be less for a watershed surface having a relatively high infiltration rate. On the other hand, such a surface would be more easily erodible and the transport capacity, roughly proportional to discharge raised to the 5/3 power, would tend to be the dominant factor.

Between one watershed and another the surface slope, area, and topography would tend to be important in explaining differences in sediment delivery.

Suspended Sediment Yield

Because it can be reasoned that the water runoff and the watershed sediment delivery are closely linked, studies of suspended sediment yield focus first on the relationship between those two variables. In an early study of the Red River near Denison, Texas, Campbell and Bauder found

$$G_s = MQ^n, \qquad \ldots[1.1]$$

where G_s = suspended sediment discharge in tons/second, Q = water discharge in cubic feet/second, M = coefficient and n = 2.036, a relationship which closely described the suspended land conditions at that station (9).

Equation [1.1] was then used to calculate the daily loads of sediment for a period of 60 months during 1930-1938. The total calculated delivery over the period as compared with daily measurements made by the Department of Agriculture differed by only 1.5 percent. It appears that there is a considerable variation between individual measurements and the rating curve and that some of the longer term comparisons differ by 25

percent from the daily measurements. Nevertheless these variations were averaged out over the entire 60 months.

A study by Parsons, Apmann, and Decker (10) of suspended sediment delivery in the Buffalo River, N.Y., watershed considered the effect of other variables on sediment yield. These included seasonal variability, which also indirectly included the factors of temperature and antecedent moisture. It was found that the nature of precipitation, whether in the form of snowmelt or rainfall, had no measurable effect on sediment yield. Rainfall intensity also seemed to play no part in the process. This finding does not contradict the previous discussion on watershed erosion, but rather amplifies it, since the watershed which was studied has an area of some 300 square miles, sufficiently large so that it acts to filter out the effects of intensity. These are felt strongly in the small experimental plots which have been the source of much soil erosion data. Sediment yield decreased with decreasing length of eroding banks, indicating that a significant amount of sediment was produced from the stream channel itself. Another important influence on yield was found to be the source area of the storm; those originating in the upper part of the watershed provided nearly twice the sediment concentration for a given event as those which came from the lower sector. At least part of this difference can be attributed to attenuation of flood peaks. Localized storms of a given rarity will produce lower rates of flow at the gaging station as they are farther removed from the station. In addition, slopes are steeper in the headwaters, giving greater potential for both soil detachment and transport. Since the wash load rarely, if ever, approaches the transport capacity of the stream, the attenuated flow

from upstream will continue to carry much of its load into the lower portions of the watershed even as the water discharge increases.

A study by Striffler of the Tobacco River Watershed in central Michigan indicated that sediment load depended on water discharge, length of eroding banks, soil types, and whether the stream was rising or falling (11). Other analyses have yielded similar conclusions.

One approach of determining trends in sediment yield is to develop a simulation method. If this is successful we should be able to relate sediment load to the important processes which are taking place, and to show whether an orderly variation in load exists. Another approach is to study the annual values for sediment load and determine whether they change with time. We will first consider how to develop a simulation technique, and for this we start with the principle of conservation of mass as expressed by the continuity equation for watershed sediment.

Watershed Sediment Continuity

To make an accounting of the sediment mass in a watershed requires that the instantaneous rate of change of watershed sediment volume be equal to the difference between the inflow and outflow of sediment mass. This is the continuity, or conservation of mass, principle for the sediment. An upstream watershed will be considered; one which has no inflowing tributaries to deliver sediments. Other sources, such as dustfalls and transports of sediments for construction purposes, will be neglected. In this case, therefore, inflows will be equal to zero. The equation describing continuity is

$$\rho \frac{dV}{dt} = -g(t), \qquad \text{...[1.2]}$$

in which ρ = sediment mass density, V = watershed volume, a function of time, and g(t) = outflow rate. Under these conditions, equation [1.2] states that the long-term trend is for degradation of the watershed.

The watershed volume can be thought of as existing in two phases, one of which is the in-place or deposited sediments, termed the base volume, and the other, the sediments which are in transport at the given instant; thus

$$V = B + M \qquad \text{...[1.3]}$$

The rate of change of base volume, B, with time is also the net rate of accretion of material in the watershed (Figure 1.1). This accretion rate equals the difference between deposition rate and erosion rate:

$$\rho \frac{dB}{dt} = d(t) - e(t) \qquad \text{...[1.4]}$$

Both d(t), the deposition rate, and e(t), the erosion rate, represent processes which are underway simultaneously in different areas of the watershed. Furthermore it is possible that some parts of the watershed experience neither deposition nor erosion at a given instant.

The base volume of the watershed can also be considered as the product of its surface area, A, and its mean, or average, elevation, $\bar{h}$. The surface area in most cases does not change significantly during the time periods being considered, and the accretion rate can be replaced by the denudation rate, $-d\bar{h}/dt$, so that

$$-\rho A \frac{d\bar{h}}{dt} = d(t) - e(t) \qquad \text{...[1.5]}$$

integrating over a storm period or other convenient and meaningful time period, Δt, yields:

$$\rho A(\bar{h}_2 - \bar{h}_1) = -E' \qquad \text{...[1.6]}$$

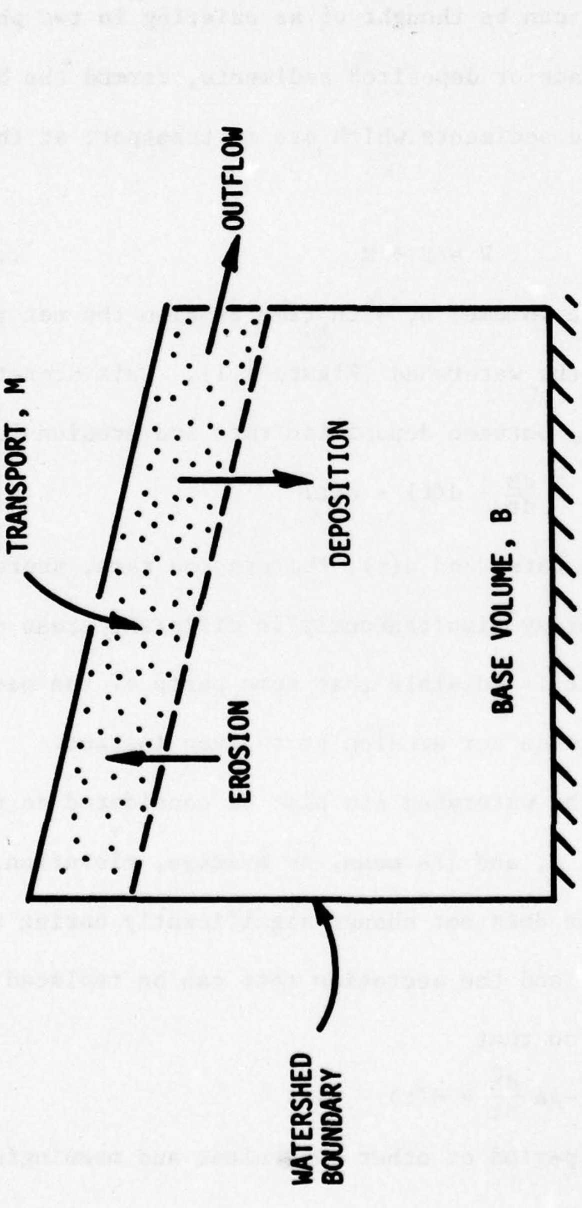

Fig. 1-1 DEFINITION SKETCH FOR CONSERVATION OF SEDIMENT MASS PRINCIPLE

with $\bar{h}_2$ and $\bar{h}_1$ being the average watershed elevations after and at the beginning of the period, and E' being the total net erosion. That equation states that the change in watershed elevation is capable of being expressed as an amount of net erosion.

The combination of the first three equations yields

$$\rho \frac{dM}{dt} = e(t) - d(t) - g(t); \qquad \text{...[1.7]}$$

the relation between change in volume of transported material to the net erosion rate, $e'(t) = e(t) - d(t)$, and the outflow. An alternative expression can be derived by substituting Eqn. [1.5]:

$$\rho \frac{dM}{dt} + \rho A \frac{d\bar{h}}{dt} = -g(t) \qquad \text{...[1.8]}$$

or, by rearranging the terms, the outflow from the watershed is

$$g(t) = \rho \frac{d}{dt} (M + A\bar{h}) \qquad \text{...[1.8]}$$

The continuity equation for sediment expressed as either a function of net erosion or denudation rate ought to form the basis of any rational method for estimating sediment yield. Ideally, the local rates at which the erosion, deposition, and transport processes occur should be expressed analytically and included in the framework of the equation. These rates are very complicated and depend on the local watershed characteristics as well as the erosion and transport capacities and limits of the agents.

Further Development of a Simulation Method

The simplified water budget for a watershed can be expressed in a form similar to equation [1.7]:

$$\frac{ds}{dt} = P(t) - Q(t) \qquad \ldots[1.10]$$

in which s = storage, P(t) = effective precipitation, and q(t) = runoff. Furthermore, the mass of sediment in transport is M=cs, with c being an average concentration of sediment in transport. Combining the several equations we have

$$\frac{dc}{dt} + \left(\frac{1}{s}\frac{ds}{dt}\right)c = \frac{e(t) - d(t) - g(t)}{s} \qquad \ldots[1.11]$$

One way of approaching hydrographic analysis is through the expansion of the water budget equation in time derivatives of precipitation and runoff (12).

In an analogous way, we could consider the sediment balance equation to depend on several Taylor series expansions of precipitation and runoff. This concept considers precipitation and runoff to be the active agents in the sediment transportation process. With those inputs, the output is the variation of sediment load with time. With precipitation as an input one of the outputs is water runoff. This approach neglects the internal dynamics of the watershed and assumes a similarity in the processes over a time period.

If each of the variables, c, s, and e can be described by a Taylor series expension in P and q, and d in an expansion of q alone, the

result is that g becomes a function of P and q, their derivatives, their powers and the products of those variables. Because it was too difficult to obtain data on precipitation, this input was neglected and only runoff, its derivatives, powers, and cross-products were used.

Daily sediment load was fitted against daily discharge and its first four derivatives, as computed by fifth-order averaged and sixth-order unaveraged central differences, in each of 14 years between 1951 and 1969. A time series was then determined for each of the coefficients in the quadratic model using as input the values computed in the first 13 of the 14 years. These time series were used to verify the loads for 1964 and 1966 and to predict the loads for 1969, the 14th year. The results suggested that there are no systematic trends among the model coefficients with time.

The simulations, in the best case, yielded excellent results. The R^2 value for the 1964 year was 0.9957 and the peak daily load of 51,400 tons which occurred on March 5 was matched within 1%. Some negative values of load were generated for low flows. Generally, both absolute and percentage inaccuracies were greatest with the low values. The simulations could be bettered by including even the daily amounts of precipitation and by smoothing out the loads which occurred at low flows.

In the worst case, 1966, the R^2 value reached only 0.78 and many negative values were generated. Additional factors were present in this case which worsened the simulation. These include the fact that 1966 experienced more variation and lower peak values in sediment load. We would expect that a more complex model with more coefficients would

yield better results. The quadratic model with its 20 coefficients was replaced by the cubic model with 55 and yielded an $R^2 = 0.9733$ for 1966.

Regardless of the merits of the simulation technique it is important to remember that no time trends were discovered in the coefficients. Continuing to search for those trends, the annual sediment load data was regressed against time. This also failed to demonstrate any time trends. Furthermore, measurements of sediment load were taken in 1902, 1903, and 1904 on the Cuyahoga River by the U.S. Army Engineers. Although their methods were not the same as nowadays, and not as precise, measurements were taken every day, so that the total load for the year may not be too inaccurate. For the water year 1902-1903 a total of 386,000 tons of suspended sediment was measured from a drainage area of 778 square miles. This is equivalent to a load of 351,000 tons passing the gaging station at Independence. Compared to the 21 recent years of data, the 1902 water year would be the second largest annual load measured, but the equivalent water discharge of 412,000 cfs-days would be the third largest year for water yield. The ratio of load to discharge falls within the probable error of the modern measurements so that we conclude that the 1902 water year measurements were not significantly different than present loads.

Sedimentation Rates in Lake Erie

The sedimentation rates in Lake Erie have been analyzed by Kemp, et al. (13), (14) from ten sediment cores taken in 1970 and 1971. On the basis of changes in concentration of chestnut (castanea) and ragweed (ambrosia) pollens, two time periods were delineated. The rapid

rise of ragweed pollen was taken as the beginning of the period of rapid agricultural development about the year 1850. The decline of chestnut pollen marked the year 1935, the time when a fungus disease attacked that species.

Sedimentation rates since 1935 ranged from 394 to 5,049 gm/m^2/yr., the highest values of the several Great Lakes. Those rates are up to 3 times greater than sedimentation rates in the "Early Colonial" period, 1850-1935. Table 1.2 compares the average rates in the two periods. The accumulations at all the 10 sites average 4.4 mm/year for the present day rate. An approximate idea of the average postglacial rate can be obtained: approximately 1 mm/year for the 5 cores of Table 1.2. The Early-Colonial rate was approximately 3.0 mm/year for the same 5 cores and the present day rate for the same 5 is 7.1 mm.

Conflicts in the Trend Analyses

Although our analysis of the daily suspended sediment records of the Cuyahoga River has shown no time trends in load delivery since 1950 and has demonstrated that measurements taken in 1902 can be considered part of the same population of data, five sediment cores from Lake Erie indicate distinct trends in sediment inflow to the lake.

There are several reasons to explain these differences:

1. Suspended sediment load is only one component of the total load delivered to the lake. Shoreline erosion is also important, and it is possible that shoreline erosion has increased since 1850 due solely to higher water levels. These higher levels would have accompanied the significantly greater surface runoff produced after 1850 with the

Table 1.2 PRESENT-DAY AND EARLY-COLONIAL SEDIMENTATION RATES AT SAMPLE LOCATIONS IN LAKE ERIE

Station Location	Present Day Sedimentation Rate $g/m^2/yr$	Early-Colonial Sedimentation Rate $g/m^2/yr$	Present Day Rate/ Early-Colonial Rate
4	3580	1158	3.1
5	3465	1433	2.4
7	1109	854	1.3
8	1190	391	3.0
9	5049	2329	2.2

Source: A. L. W. Kemp, et. al. (13)

destruction of the forests.

2. The location of the sediment measuring station on the Cuyahoga River is upstream from the urbanizing area of Cleveland. It does, however, include some urbanizing regions of Akron and upstream areas. The impact of some of this has been mitigated by reservoir construction in the headwaters. More soil conservation measures have been instituted in rural areas. The substantial amounts of industrial sediments flowing into Lake Erie are not measured.

3. The comparison of only one year, 1902, with modern times can be misleading. A more certain comparison could be made if we had available several more years of record.

4. The trends indicated by the cores depend on locating more or less precisely the two pollen horizons. That does not always appear to be a simple determination.

Sediment Load to Lake Erie

The total sediment load carried to Lake Erie by its tributaries consists of both the measured and unmeasured load. Table 1.1 lists 9 stations at which daily suspended sediment measurements have been accumulated for a total of somewhat more than 70 station years of record. The partial measurements at the remaining stations form an incomplete and scanty set of data. The accumulation of sediments in 35 reservoirs in the area has been tabulated (15). Apart from these measurements, there does not appear to be any other significant data on tributary inflows to the lake.

The total suspended load will be estimated from a nonlinear re-

gression of the available daily measurements and the average annual total load estimated from the reservoir surveys. Unless complete and detailed measurements are made of the sediments, morphology, and geometry of each tributary the task of estimating total load is very imprecise. Even with such complete data the results will have a wide variability since the sediment transport equations which are used for the calculations might not apply to the given case.

Estimates of Annual Suspended Load Delivery

The annual sediment loads for the Cuyahoga, Maumee, Sandusky, and Portage Rivers in Ohio and Big Creek, Big Otter Creek, and Sturgeon Creek in Ontario were analyzed using 67 available station years. The nonlinear regression program NLIN2 was used to fit load against the products of powers of population, watershed slope, watershed area, and annual water discharge. The statistically best relationship was between load and discharge only:

$$G = B(1)Q^{B(2)} \qquad \text{...[1.12]}$$

With G = annual suspended sediment load, tons/yr., Q = annual discharge, cfs-days. The best fit values for B(1) and B(2) were 0.704 and 0.998, respectively, and the nonlinear confidence limits give the range of values for the two parameters as $0.658<B_1<0.749$ and $0.990<B_2<1.000$. The nonlinear confidence limits include approximately 97% of the expected deviation. The regression explained better than 91% of the variance in the data.

There is significant similarity among the tested river basins in terms of their response to hydrologic events. The average hydrographs

of some rivers in the basin have been compared (16). These hydrographs are the ratios of average monthly discharge to average annual discharge. There is little difference in the curves for the streams in Ohio and Ontario apart from January and February flows. By plotting the suspended sediment load against water discharge the similarity in load delivery is also evident (Fig. 1.2). However, in adding the sediment measurements from the River Raisin, Michigan, it is apparent that this latter watershed has significantly different sediment generating characteristics. This is due to the topographic and geologic differences of that basin, since a substantial area lies in the "pot and kettle" region. Numerous small lakes provide additional storage for the runoff water and sediment.

Thus, in estimating the suspended sediment yields to the lake the Michigan tributaries were segregated. The River Raisin was considered typical of those four watersheds. It was further assumed that the annual load-discharge relationship would have the same slope, or value of B(2) in equation [1.1], as the other basins in Ohio and Ontario. In order to determine the best fit coefficient for that river the sums of the squared deviations between the predicted and the actual loads must be minimized.

Thus:

$$\frac{d}{da}\left[\sum^{n} H_j^2 - a(2\Sigma^{n} J_j H_j) + a^2 \sum^{n} J_j^2\right] = 0 \qquad \text{...[1.13]}$$

and, therefore,

$$a = \frac{\sum^{n} J_j H_j}{\sum^{n} J_j^2} \; ; \quad \left[J_j = Q_j^b\right] \; ; \qquad \text{...[1.14]}$$

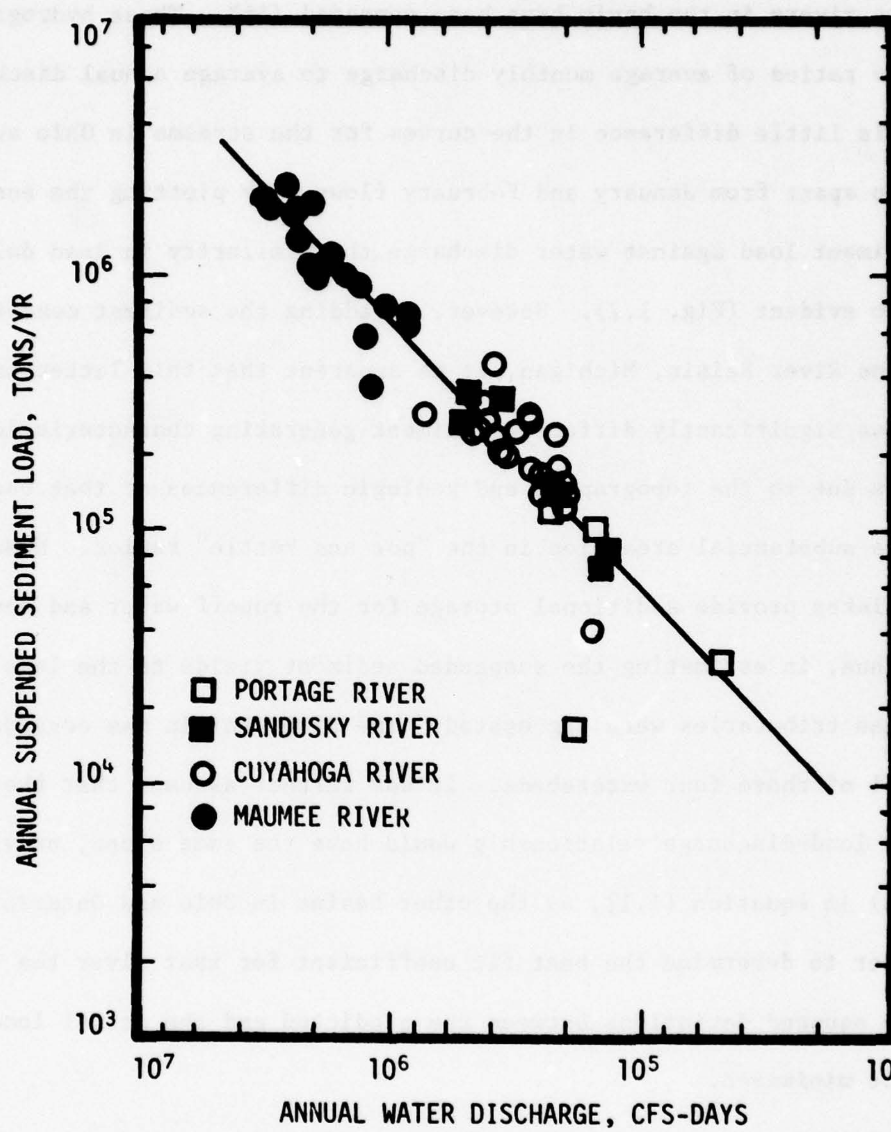

Fig. 1-2 REGIONAL REGRESSION OF ANNUAL LOADS

in which H_j = measured annual load for year j, Q_j = measured annual water discharge, b = exponent derived for other Lake Erie watersheds (value of B(2)), and a = coefficient in relation $G = a\ Q^b$.

Employing the 5 available years of data from 1967 through 1971 an average value of a = 0.285 was calculated, with a range of 0.278 to 0.315.

Equation [1.12] was then applied to each tributary to the lake and an average annual suspended load figure calculated. From the combinations of the smallest values of the coefficients and the largest both an expected lower limit and an expected upper limit were calculated. For the four Michigan tributaries the average value of B(1) = 0.285 was used. For all other streams the value of B(1) was 0.704. The same value of B(2) was used for all the streams. The calculations are summarized in Table 1.3.

The average annual load calculated in this way is 4,570,000 tons/year and the limits range between 4,060,000 and 4,930,000 tons/year. These figures are equivalent to annual inputs of 4,140,000, 3,680,000 and 4,470,000 metric tons.

Although the total sediment yields appear reasonable, the calculated values from Table 1.3 must not be used to represent the loads from individual streams, since the relationship of equation [1.12] was derived by a statistical analysis.

The average annual load of 4,570,000 tons compares closely with the value of 4,460,000 tons tabulated by Herdendorf (17), but the values for individual streams are significantly different. Table X from Herdendorf's analysis has been included here for comparison as Table 1.4. An additional column, Suspended Load per Unit Area, has been added.

Table 1.3 ESTIMATED SUSPENDED SEDIMENT LOAD FROM LAKE ERIE BASIN

		Avg. Daily Discharge	Lower Limit	Average	Upper Limit
US-Mich	Huron R.	495	50,228	50,857	53,557
	U.	153	15,525	15,753	16,750
US-Mich & Ohio	Raisin R.	600	60,882	61,622	64,792
	U.	244	24,759	25,106	26,587
US-Mich, Ind & Ohio	Maumee R.	4350	960,777	1,099,202	1,189,225
	U.	226	51,414	57,447	61,785
	Portage R.	373	84,433	94,718	101,973
	U.	115	26,340	29,271	31,439
	Sandusky R.	1180	264,047	298,953	322,594
	U.	203	46,232	51,611	55,497
	Huron R.	269	61,090	68,353	73,541
	U.	65	14,973	16,564	17,770
	Vermillion	202	46,006	51,358	55,224
	U.	60	13,832	15,292	16,403
	Black R.	303	68,730	76,974	82,836
	U.	46	10,632	11,730	12,576
	Rocky R.	248	56,367	63,027	67,799
	Cuyahoga	820	184,159	207,898	224,176
	U.	94	21,573	23,936	25,698
	Chagrin	310	70,302	78,749	84,749
	U.	33	7,653	8,421	9,022
	Grand R.	755	169,702	191,450	206,406
	U.	145	33,134	36,890	39,641
US-Ohio & Penn	Ashtabula	165	37,655	41,968	45,109
	Conneaut Ck.	288	65,361	73,171	78,735
US-Penn	U.	537	121,114	136,264	146,808
US-N.Y.	U.	494	111,509	125,373	135,052
	Cattaraugus Ck.	900	201,938	228,139	246,047

Table 1.3 (continued)

		Avg. Daily Discharge	Lower Limit	Average	Upper Limit
US-N.Y. (cont'd)	Eighteen Mile Ck.	494	111,509	125,373	135,052
Canada-Ontario	U.	74	17,024	18,852	20,230
	Grand R.	2410	535,445	609,702	658,858
	U.	157	35,847	39,937	42,921
	Nanticoke Ck.	72	16,568	18,344	19,684
	Lynn R.	88	20,210	22,411	24,058
	Young R.	65	14,973	16,564	17,770
	Dedrich Ck.	60	13,832	15,292	16,403
	Big Ck.	225	51,189	57,193	61,512
	U.	54	12,462	13,766	14,763
	South Otter Ck.	48	11,090	12,239	13,122
	Big Otter Ck.	298	67,607	75,706	81,469
	Catfish Ck.	153	34,943	38,921	41,828
	Kettle Ck.	165	37,655	41,968	45,109
	U.	203	46,232	51,611	55,497
	U.	128	29,286	32,573	34,993
			4,064,049	4,574,399	4,930,169

Notes: 1. U. = Tributary name omitted

2. Average daily discharge obtained from Table

Table 1.4 RUNOFF DATA FOR STREAMS TRIBUTARY TO LAKE ERIE (17)

	Drainage Area (sq. mi.)	Average Discharge (cu.ft/sec)	Estimated Suspended Solids (tons/year)	Estimated Dissolved Solids (tons/year)	Susp. Load Per Unit Area (tons/yr/sq. mi.)
Streams in Michigan					
Detroit River	----	176,000	1,570,000	33,580,000	
Huron River	890	570	1,800	73,000	2.0
Raisin River	1,020	673	4,700	91,200	4.6
Others	1,200	720	4,000	25,000	3.3
Streams in Ohio					
Ottawa River	180	119	1,000	5,000	5.6
Maumee River	6,586	4,740	2,270,000	1,370,000	345.
Toussaint River	108	76	700	4,000	6.5
Portage River	587	392	120,000	91,200	204.
Sandusky River	1,421	1,060	270,000	446,400	190.
Huron River	403	310	12,000	50,000	30.
Vermilion River	272	218	9,000	40,000	33.
Black River	467	388	15,300	66,400	33.
Rocky River	294	275	29,500	131,400	100.
Cuyahoga River	813	800	260,000	419,800	320.
Chagrin River	267	315	35,000	90,000	130.
Grand River	712	769	212,000	1,340,000	300.
Ashtabula River	136	166	5,500	32,000	40.
Conneaut Creek	192	235	4,000	20,000	20.
Others	1,100	880	200,000	300,000	180.
Streams in Pennsylvania					
Otter Creek	176	200	4,000	20,000	20.
Others	193	219	4,500	25,000	23.
Streams in New York					
Cattaraugus Creek	500	800	137,600	226,700	275.
Buffalo River	375	545	74,500	357,300	199.
Others	325	488	60,000	150,000	185.

Table 1.4 (continued)

	Drainage Area (sq. mi.)	Average Discharge (cu.ft/sec)	Estimated Suspended Solids (tons/year)	Estimated Dissolved Solids (tons/year)	Susp. Load Per Unit Area (tons/yr/sq. mi.)
Streams in Ontario					
Grand River	3,000	2,490	375,000	500,000	125.
Others	3,160	2,530	350,000	450,000	110.
Totals for Lake Erie Tributaries	24,357	195,978	6,030,100	39,859,400	
Municipal and Industrial (*outflow* direct to Lake Erie)	----	----	87,200	179,000	
Precipitation over Lake Erie	9,919	23,300	----	----	
Grand Totals for Lake Erie	34,276	219,278	6,117,300	40,038,400	

Data Sources: U.S. Geological Survey; Ontario Water Resources Commission; Ohio Department of Natural Resources; and Federal Water Pollution Control Administration.

There are a few other sources of suspended load estimates. Two of these are tabulated (Table 1.5 and 1.6) in order to show the substantial differences that arise from the several analyses. Table 1.5 is the computed annual average sediment discharges of streams in the Erie-Niagara basin (18), while Table 1.6 is the net sediment yields of major rivers in the Lake Erie Basin (19). Compare the yields of sediment from Cattaraugus Creek, for example. From Equation [1.12] the yield is 410 tons/sq. mi., and Herdendorf's result gives 275. Archer and LaSala, from the only measurements taken of load, arrived at a suspended sediment yield at Gowanda of 1280. The Great Lakes Basin arrived at a yield of 33 tons/sq. mi./yr.

It seems evident that considerably more data needs to be taken on the unsampled streams in the basin in order to more adequately define the sediment yields from each basin. Nevertheless, the values for total suspended load which is carried to the lake are undoubtedly close to the actual situation.

Estimates of Annual Total Load Delivery

The total sediment load carried by a tributary to Lake Erie is the sum of the suspended sediment load and the unmeasured load. Although the data available on suspended load has been tabulated we would like to analyze the unmeasured input from each of the rivers and streams which enters the lake. For example, consider in very abbreviated form the case of the Cuyahoga River.

Sediment Production from the Cuyahoga River

Suspended sediment measurements are made at Independence, where the

TABLE 1.5 **Computed annual average sediment discharges of streams in the Erie-Niagara basin (18)**

Sampling point mileage index number	USGS station number	Stream and location	Drainage area (sq mi)	Number of measurements	a/ Computed annual average sediment discharge: Tons	a/ Computed annual average sediment discharge: Tons per sq mi
E23(54.7)	2134.1	Cattaraugus Creek near Arcade	78.4	11	33,000	420
E23-48(0.6)	2134.2	Elton Creek at The Forks	71.6	10	--	--
E23-33(0.4)	2134.5	Buttermilk Creek near Springville	29.3	8	38,000	1,300
E23-20(14.4)	2134.9	South Branch Cattaraugus Creek near Otto	25.4	5	--	--
E23(17.4)	2135	Cattaraugus Creek at Gowanda	432	14	610,000	1,400
E23-6(0.9)	2140.1	Clear Creek near Iroquois	55.8	3	--	--
E20(2.2)	2140.6	Big Sister Creek at Evans Center	48.4	1	--	--
E13(15.3)	2142	Eighteenmile Creek at North Boston	37.2	14	29,000	780
E13-4(2.9)	2142.3	South Branch Eighteenmile Creek at Eden Valley	36.3	13	--	--
E13(0.5)	2142.4	Eighteenmile Creek near Highland-on-the-Lake	119	2	--	--
E2(3.5)	2142.5	Smoke Creek at Lackawanna	14.6	1	--	--
E1(31.8)	2144	Buffalo Creek near Wales Hollow	80.1	8	20,000	250
E1(10.4)	2145	Buffalo Creek at Gardenville	144	62	150,000	1,000
E1-6-7(2.9)	2149.8	Little Buffalo Creek near East Lancaster	23.9	2	--	--
E1-6(11.0)	2150	Cayuga Creek near Lancaster	94.9	56	110,000	1,200
E1-4-15(0.5)	2152.5	West Branch Cazenovia Creek at East Aurora	58.6	4	--	--
E1-4-14(8.1)	2153.5	East Branch Cazenovia Creek at South Wales	38.0	7	--	--
E1-4(4.1)	2155	Cazenovia Creek at Ebenezer	134	55	200,000	1,500
0158-15(6.8)	2162	Scajaquada Creek at Buffalo	15.9	4	--	--
0158-12(100.6)	2164	Tonawanda Creek near Johnsonburg	23.6	5	5,900	250
0158-12-32(10.5)	2165	Little Tonawanda Creek at Linden	22.1	7	1,100	50
0158-12(68.7)	2170	Tonawanda Creek at Batavia	171	20	60,000	350
0158-12(46.9)	2175	Tonawanda Creek at Alabama	231	6	37,000	160
0158-12(19.5)	2180	Tonawanda Creek at Rapids	352	12	32,000	90
0158-12-1(28.8)	2184.5	Ellicott Creek at Mill Grove	40.7	13	3,100	80
0158-12-1(14.1)	2185	Ellicott Creek at Williamsville	72.4	12	4,300	60

a/ Includes 10 percent of the calculated suspended-sediment discharge for bedload estimate

Table 1.6 NET SEDIMENT YIELDS FROM MAJOR RIVERS IN THE U.S. PORTIONS OF THE LAKE ERIE AND LAKE ONTARIO DRAINAGE BASINS (19)

River	Total yield (T/yr)	Yield per unit area (T/mi^2-yr)
Huron River	65,100	77
Raisin River	118,800	94
Maumee River	1,179,000	173
Portage River	89,000	180
Sandusky River	226,000	161
Black River	67,100	142
Cuyahoga River	200,600	254
Grand River	22,500	34
Cattaraugus Creek	18,000	33
4 small streams near Buffalo	23,000	65
5 samll streams near Buffalo	24,000	40
Genesee River	76,000	31
Oswego River	136,500	27

Data from Great Lakes Basin Commission Erosion and Sedimentation Work Group, 1970. Total Yields based on extrapolations from data stations in the drainage basins. Effects of coastal cities are unknown.

watershed area is 707 sq. mi. Another 103 sq. mi. of area is added downstream to the harbor mouth. The average suspended load passing Independence in the period 1951-1970 was 211,000 tons/yr. Additional unmeasured load was carried, estimated to be about 150,000 tons/yr, for a total of 360,000 tons/yr (20).

This figure has been extrapolated to a total of 440,000 tons/yr carried to the Harbor from upland sources, a yield of approximately 540 tons/sq. mi./yr. from the Cuyahoga Basin. Not all this sediment reaches the lake, for in the period 1959-1968 about 380,000 tons/yr of fluvial sediments were dredged from the Harbor (21).

These numbers were derived from measurements of dredged materials and estimates of harbor trap efficiency. Comparisons were made with the estimates of transport capacity in the Cuyahoga River above Independence. Because of the lack of adequate data on bed material size distribution in channel and similar characteristics, the calculated amounts of sediment yields can only be considered approximate.

Differences in sediment yields within the basin were found to be significant. The major upstream reservoir, Lake Rockwell, has a drainage area of 204 sq. mi. and the sediment production of that watershed is 206 tons/sq. mi./yr. About 10% of that sediment is not trapped in the lake. Continuing downstream, the annual yield between Lake Rockwell and Old Portage is 38 tons/sq. mi. Much of that watershed has been developed as urban area. Tinker's Creek above Bedford produces 293 tons/sq. mi./yr., and the remaining area of the basin above Independence has a yield of 798 tons/sq. mi./yr.

Reservoir Surveys

In this study the tributary sediment load to Lake Erie was estimated from reservoir survey data. The average rate of sediment accumulation has been measured and reported for a number of impoundments in the Great Lakes Drainage Basin (22). Thirty-five of these were in the Lake Erie Basin or in the nearby Western Lake Ontario Basin. The following information was tabulated (Table 1.7): net drainage area, total accumulation time, average accumulation rate, and ratio of reservoir capacity to annual inflow.

The total sediment yield of each contributing watershed is not necessarily trapped completely by a reservoir. If it has a small capacity relative to the annual inflow, or if the watershed yields relatively large amounts of fine materials, the trap efficiency will be less than 100%. The geometry of the reservoir also influences trap efficiency. Two methods are commonly used in the United States for estimating this efficiency; one formulated by Bruun and the other by Churchill (23). It is believed that Churchill's method is more precise, but it requires data on reservoir geometry that was not available. Therefore, Bruun's method was used, in which trap efficiency is a function of the ratio of capacity-inflow, and for each of the thirty-five impoundments the efficiency was estimated. The procedure was simply to obtain a value for the trap efficiency at the beginning of the survey from the chart prepared by Bruun and a second value at the end of the survey period. The two were averaged. The total watershed yield was subsequently calculated as the average accumulation divided by trap efficiency. The precision of the yield figures is probably no better than one significant figure,

Table 1.7 RESERVOIR SEDIMENTATION SURVEYS MADE IN THE LAKE ERIE BASIN THROUGH 1970

Reservoir	Minor Drainage	Net Drainage Area (sq mi)	Survey Dates	Period Between Surveys (years)	Averate Annual Accumulation (tons/sq mi/yr)	Capacity/ Inflow (ac ft/ac ft)	Estimated Trap Efficiency (%)	Adjusted Average Annual Yield (tons/sq mi/yr)
OHIO								
Lake Rockwell	Cuyahoga	124.1	1914-1950	36	120		90.5	130
East Branch	Cuyahoga	16.88	1939-1949	9.7	661		98	670
Grand Lake St. Marys	Maumee	93	1844-1940	96	3,162		100	3,162
Goller Pond	Maumee	.024	1945-1951	6.4	902	0.761-0.753	99	910
Eagle Creek	Maumee	5.20	1912-1951	39	347	.050-0.29	76	460
Beetree Creek	Maumee	1.91	1912-1951	39	675	.156- .109	92	730
Sixmile Creek	Maumee	21.4	1912-1951	39	343	.094- .066	86	400
Batt Pond	Maumee	.012	1947-1951	4.3	4,396	.417- .401	98	4,490
Harrison Lake	Maumee	37.0	1941-1949	8.3	232	.048	79	330
			1949-1951	2.1	392			
	Weighted Average		1941-1951	10.4	264			
Allmandinger	Maumee	.035	1945-1951	6.7	2,001	.239- .221	96	2,080
Bucyrus No. 2	Sandusky	2.79	1919-1949	30	277	.120- .108	91	300
Contris Pond		.13	1947-1951	4	3,270			
			1951-1954	3	1,460			
	Weighted Average		1947-1954	7	2,490	.133- .107	91	2,700
Burt Lake		.74	1948-1951	2.8	924	.155- .150	93	990
Kohart Pond		.019	1943-1951	7.8	301	.229- .219	96	310

Table 1.7 (continued)

Reservoir	Minor Drainage	Net Drainage Area	Survey Dates	Period Between Surveys	Averate Annual Accumulation	Capacity/ Inflow	Estimated Trap Efficiency	Adjusted Average Annual Yield
		(sq mi)		(years)	(tons/sq mi/yr)	(ac ft/ac ft)	(%)	(tons/sq mi/yr)
				OHIO (cont.)				
Van Buren Lake	Maumee (Flanchard)	22.72	1939-1948	9.5	233			
			1948-1951	2.8	391			
	Weighted Average		1939-1951	12.3	270	.022- .017	62	440
				MICHIGAN				
Stronach	Manistee River	233	1912-1953	41	154	.003- .0001	8	1,900
Norvell L.	River Basin	25.3	-1969	100+	43	.026- .018	64	70
Sharon Hollow	"	25	1927-1969	42	72	.016- .009	52	140
Brooklyn Mill Pond	"	6.2	1948-1969	21	457	.016- .012	54	850
Manchester Power Dam	"	6.4	1945-1969	23	137	.09 - .08	44	300
Phoenix Pd.	Middle River Rouge	56.85	-1969	100	8.8	.0074- .0056	36	24
Saline Mill Pd.	Saline R	63	1937-1969	31	54	.0061- .0033	27	200
Bridgeway L,	(nr. Dexter)	7.5	1927-1969	41	93	.0250- .0156	62	150

Table 1.7 (continued)

Reservoir	Minor Drainage	Net Drainage Area	Survey Dates	Period Between Surveys	Averate Annual Accumulation	Capacity/ Inflow	Estimated Trap Efficiency	Adjusted Average Annual Yield
		(sq mi)		(years)	(tons/sq mi/yr)	(ac ft/ac ft)	(%)	(tons/sq mi/yr)
				MICHIGAN (cont.)				
Franklin Mill Pd.	Franklin Br, Rouge	7.8	1833-1969	136	86	.0133- .0018	28	300
Waterford Pd	Middle River Rouge	54	-1969	100	11	.0067- .0039	22	50
Tecumseh Mill Pd	Evans Ck	26.3	1827-1969	142	45	.01501- .0062	46	100
Belleville Lk	Huron R	(20.3)*	1929-1949	40	3,637	.0513- .0462	100	3,637
Ford Lake	Huron R	(11.2)*	1933-1969	36	8,045	.0472- .0424	100	8,045
Barton Pond	Huron R.	(183)*	1915-1969	54	46	.0083- .0068	41	110
Redmill Pd	U. Raisin	25.9	-1969	100	118	.0081- .0040	34	350
Newburgh Lk	M. Rouge	54.3	1933-1969	36	65.96	.026- .022	54	120
Lk. Adrian	Wolf Ck	59	1942-1969	28	147	.032- .027	71	200
Manchester Mill Pd	R. Raisin	17	1906-1969	63	8	.0026- .0013	6	130
				NEW YORK				
Orchard Park	Pipe Creek	1.67	1928-1951	23	’300		90	330

*Area below upstream dam.

Table 1.7 (continued)

Reservoir	Minor Drainage	Net Drainage Area	Survey Dates	Period Between Surveys	Averate Annual Accumulation	Capacity/ Inflow	Estimated Trap Efficiency	Adjusted Average Annual Yield
		(sq mi)		(years)	(tons/sq mi/yr)	(ac ft/ac ft)	(%)	(tons/sq mi/yr)
				NEW YORK (cont.)				
The following sites are in the Lake Ontario Drainage								
Lake Rushford	Genesee	60.7	1925-1951	26	484		100	484
Mt. Morris	Genesee	1,011	1951-1957	5.5	419			
			1957-1963	5.9	335			
	Weighted Average		1951-1963	11.4	376			

especially in the Michigan data where trap efficiencies are low.

A regression of the logarithm of yield against logarithm of area was calculated for 18 impoundments in New York and Ohio, resulting in the equation

$$g = 810\ A^{-0.139} \qquad \text{...[1.15]}$$

in which g = yield in tons/mi^2/year, and A = area in sq. mi. The total load delivered can be calculated by multiplying by area once more, so that load is found proportional to watershed area raised to the 0.861 power. When that equation is applied to each subwatershed draining into Lake Erie, and the sum of those contributions is calculated, the total load is 7,000,000 tons/year.

As can be seen from the display of the data in Figure 1.3 there is a substantial variability in the reservoir yields, and calculating a weighted mean value of yield for the watershed could be an effective way of estimating yield. For the same 18 sites, this value is 540 tons/sq. mi./year, exactly the same as previously determined for the Cuyahoga River basin (20). This number is significantly influenced by the high yields of the Grand Lake Saint Marys. Neglecting that reservoir gives a weighted mean yield of 350 tons/sq. mi./yr.

The watersheds in Michigan also appear to have a lower yield. Three of the data points are suspect, since there is considerable upstream regulation in the particular watershed, and neglecting those three, the average yield is 130 tons/mi^2/year.

Using that weighted mean average for Michigan and the figure of 350 for the remainder of the watershed again yields a total input of

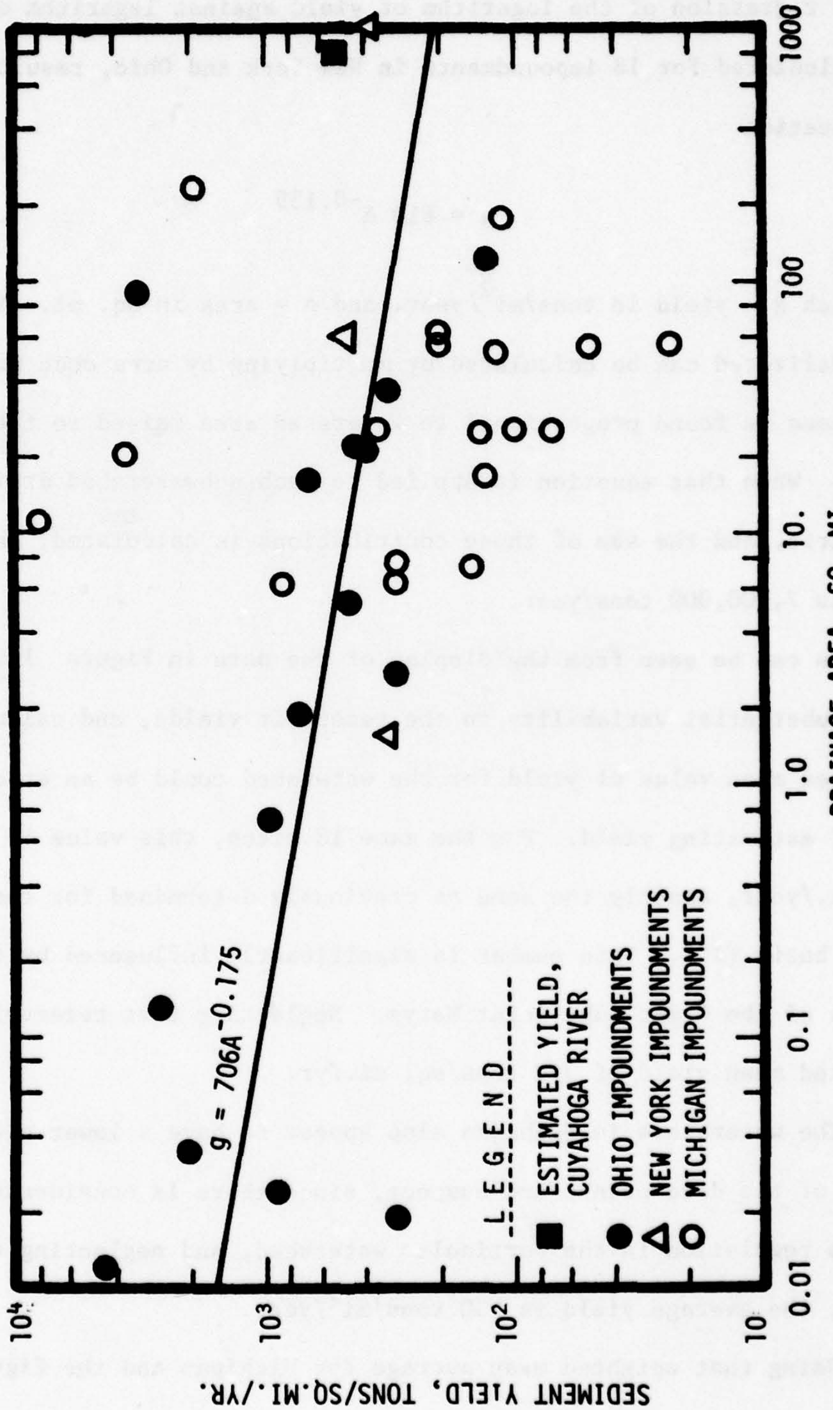

Fig. I-3 RESERVOIR SEDIMENT YIELD VERSUS DRAINAGE BASIN AREA

sediment to the lake of 7,000,000 tons/year, specifying only one significant figure.

Since it is possible to derive a number of different weighted means from the small amount of data and to apply these to the different geographic areas, several estimates of total load can be made.

Non-linear Regression

To test the variability of the data a nonlinear regression was calculated which gave the equation

$$g = 1{,}053\ A^{-0.179} \qquad \text{...[1.16]}$$

When applied to the contributing watersheds the total load becomes 7,000,000 tons, again specifying only one significant figure.

The standard error of the coefficient in equation [1.16] is ±307 and of the exponent ±0.0842. The probable errors (±50%) are therefore ±207 and ±0.0568. Associated with the latter values are the equations

$$G = 1260\ A^{.905} \qquad \text{...[1.17]}$$

and

$$G = 846\ A^{.737}, \qquad \text{...[1.18]}$$

which represent the combinations of those values leading to the highest and lowest probable values of load delivered to the lake. These are 15,000,000 and 3,000,000 tons/yr., respectively. The latter figure is less than the value derived for suspended load input to the lake, and should therefore not be considered reliable. The upper figure also seems unrealistic, but the analysis shows the wide range of values that can be

expected when even 50% confidence limits are used.

Variability Within Data

The relationship between yield and area derived by the non-linear regression, equation [1.16] was used to predict the yield values for the data itself, returning a standard error of 1,094 as compared to the mean value of 1,071 for the observed data. This indicates again the variability of the 18 data points which were used.

Part of this variability is explained by the regression itself, and part is due to the location of the impoundment within the Lake Erie Drainage Basin. Local land use and soil conditions will affect the sediment yield. However, there are also substantial differences in yield from one year to the next. Twenty-three years of data has been accumulated from Clouse Lake, Ohio, and for that period the standard deviation of the series relative to the mean yield is 62%. The suspended sediment runoff from the Cuyahoga River Basin has a comparable variability of 44%. If the yield is divided by annual water runoff, then the variability of the Cuyahoga data is reduced to 29%.

Shoreline Erosion

The largest source of fine-grained sediments to Lake Erie is shoreline erosion. Recent analyses by the Ohio Geological Survey (32) indicate long term average shoreline rates of 0.1 million tons/yr. from the New York shoreline, 0.4 million tons annually from Pennsylvania and 1.6 million tons/yr from the Ohio shoreline. Less than 100,000 tons/yr. is removed from the Michigan shoreline. Studies at the Canada Center for Inland Waters indicate that the Canadian shoreline yields an average of 25.7 million tons per year of fine-grained sediments. Summing up all of these

figures gives a total of 27.9 million tons/year.

Sediment Budget of Lake Erie

A sediment budget for the lake has been prepared by Kemp, et al. (14). The results of that analysis are displayed in Figure 1.4 and Table 1.8. The accumulation of sediments in the lake totals approximately 27 million metric tons per year (30 million tons/year), with the largest amounts being deposited in the eastern basin: 15.5 million metric tons annually (17 million tons). The central basin has an accumulation of 8.2 million metric tons per year (9 million tons) while the Western Basin accumulates 3.3 million metric tons (3.6 million tons). The most substantial input is shoreline erosion, estimated at 25.7 million metric tons/yr. (28 million tons/yr). The figures for erosion of the American shoreline give a higher total than the Ohio Geological Survey study (32).

The estimate of river inputs should be raised from 4.1 million metric tons to about 5.6 million, considering only fine-grained sediments, and to 8 million metric tons for the total inflow of bed and suspended load, including the Detroit River (8.6 million tons/year). Shoreline erosion from the American shore should be reduced to a total of 2.0 million metric tons/year (2.2 million tons/year), giving a total of 25.4 million metric tons of shoreline erosion annually.

Airborne particles and organic matter add an additional million metric tons annually, more or less. Some sediment is removed from harbors through dredging. The average annual dredging volume is almost 6,000,000 cubic yards or approximately 3,500,000 tons (3,000,000 metric tons)(24). Current practices of dredge spoil disposal probably cause

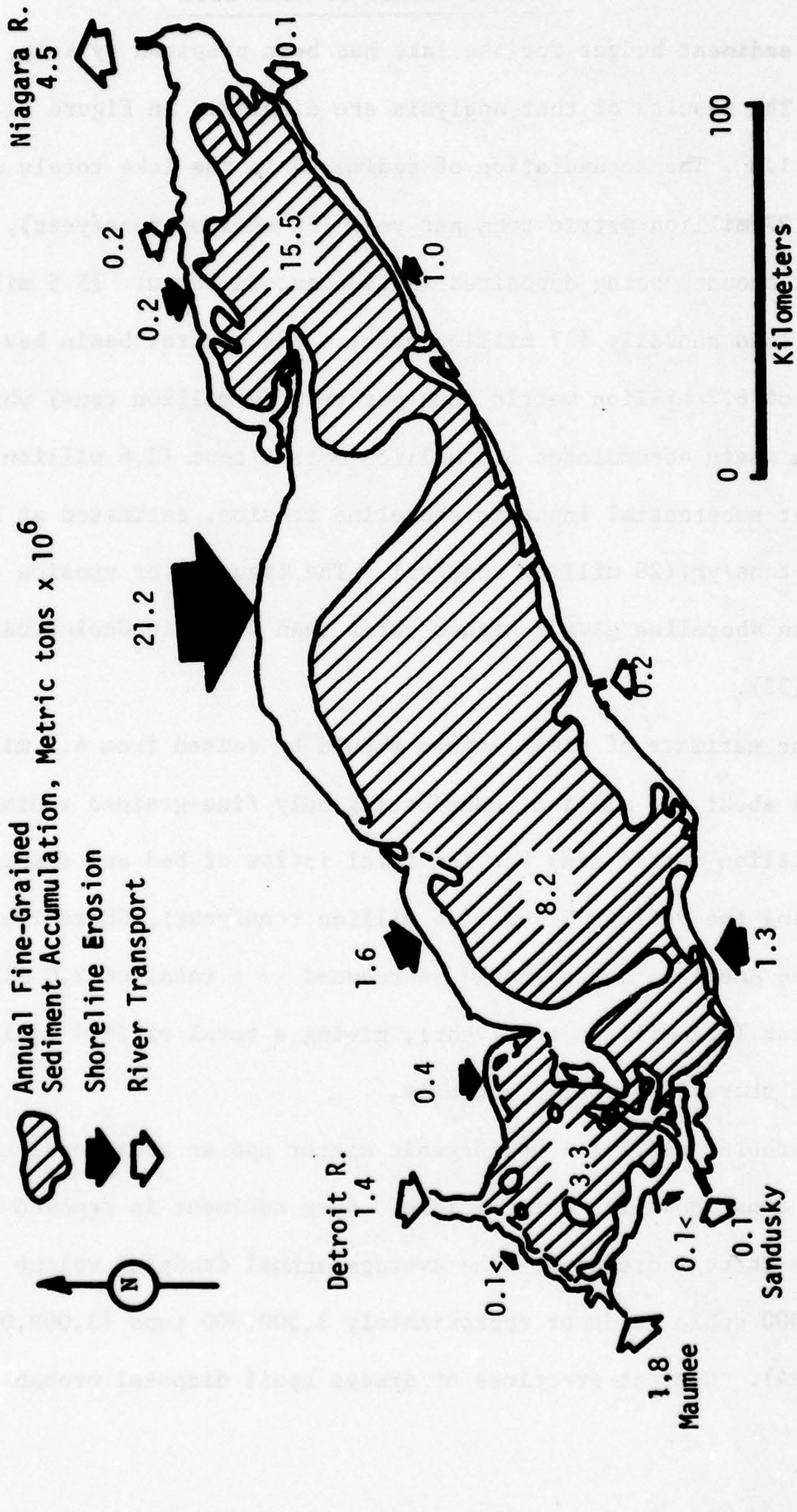

Fig. 1-4 SEDIMENT INFLOWS AND OUTFLOWS IN LAKE ERIE
From Kemp, et al (14)

Table 1.8 FINE GRAINED SEDIMENT SOURCES OF LAKE ERIE

After Kemp, et. al. (14)

Source	Zone	Yield of Fine-Grained Material Per Annum Metric tons x 10^6
Shoreline Erosion	Detroit River-Point Pelee	0.4
	Point Pelee-Erieau	1.6
	Erieau-Long Point	21.2
	Long Point-Niagara River	0.2
	Detroit River-Maumee River	[<0.1]
	Maumee River-Sandusky	<0.1
	Sandusky-Ohio-Penn. Border	1.3
	Ohio-Penn. Border-Niagara River	[1.0]
	Total	25.7
River Inputs	Detroit River	1.4
	Maumee River	1.8
	Other Rivers	0.9
	Total	4.1
Airborne Particles	Estimated Range for the Whole Lake	0.2-3.3
Autochthonous Organic Matter		1.0
Dredged Soils	Whole Lake	3.0

a removal of material rather than an addition of sediment to the lake.

Modified by the results from this study, the fine-grained sediment budget for the lake would appear as in Table 1.9 .

Net Inputs of Contaminants as Measured by Sediment Coring

The sediment accumulation data obtained by coring (3,14) also yielded information on present day loadings of some critical contaminants. These contaminants were grouped according to measured changes in concentrations over time. The groups were: conservative, enriched, nutrient, carbonate, mobile, and miscellaneous. The conservative elements were those making up the bulk of the sediment matrix (Si, K, Ti, Na, Mg, and Al). The enriched elements were Hg, Pb, Zn, Cd, Cu, Cr, and Ni. The nutrient elements were organic C, N, and P. The carbonate elements included CO_3, Ca, and Sn. Making up the mobile elements were Fe, Mn, and S, and the remaining elements, Co, Be, and V, were grouped in the miscellaneous heading.

Conservative Elements

The concentrations of those elements were found to have remained essentially constant since early colonial times, about the year 1850. Variations in concentrations about the uniform mean value imply a nonuniform rate of deposition. Aluminum was found to be strongly related to potassium and clay. The dominance of illite clays was confirmed by x-ray diffraction.

Enriched Elements

The enriched elements are characterized by small concentrations prior to about 1850 and higher concentrations near the sediment-water interface. Most of the elements are toxic in high concentrations.

Table 1.9 FINE GRAINED SEDIMENT BUDGET FOR LAKE ERIE

Inputs		Annual Yields (metric tons x 10^6)
Shoreline Erosion		25.4
River Inflows		
Detroit River		1.7
Others		5.0
Airborne Particles		±1.0
Autochthomous Organic Matter		±1.0
	Total	34.1
Outflows		
Niagara River		4.5
Dredged materials		3.0
	Total	7.5
Net Deposition		26.6
Measured Sediment Deposition		27.0

The investigators concluded that human cultural activities were the source of the sediment enrichment by those elements. The major enrichment has taken place since 1935, and it was suggested that the changes since 1950 have been most extensive.

Nutrient Elements

Surface enrichment by these elements was found, again due to human activities, leading to an increase in lake productivity. Correlations were found between P and organic carbon (OC) and between P and Fe.

Carbonate Elements

Carbonate enrichment was found in the central basin and carbonate loss in the rest of the samples.

Mobile Elements

The mobile elements are those which are capable of relatively easy migration and dissolution. Therefore little can be learned about the rate at which they are transported into the lake from sediment cores.

Miscellaneous Elements

The variability of concentrations of Co, Be and V did not show a clear trend of enrichment in the cores.

Loadings of Enriched and Nutrient Elements

The natural and anthropogenic loadings were calculated for the enriched and nutrient elements. These are summarized in Table 1.10. The natural sediment loading was calculated by multiplying the present-day sedimentation rate by the Al-normalized concentration of each element in the surface layer of the lake bottom. The anthropogenic input was calculated by multiplying the sedimentation rate by the difference between the total and normalized concentrations. Total loadings are the sum of natural and anthropogenic.

Table 1.10. NATURAL AND ANTHROPOGENIC LOADINGS OF ELEMENTS TO LAKE ERIE FROM ANALYSIS OF SEDIMENT CORES (14)

Area		Hg	Pb	Zn	Cd	Cu	Cr	Ni
		Enriched Elements						
		Metric tons per year						
Western Basin	A*	1.6	255	605	8	115	285	150
	N**	1.9	85	240	7	75	300	230
Central Basin	A	2.6	720	1650	19	235	635	240
	N	1.5	170	690	9	205	755	630
Eastern Basin	A	4.3	1335	3315	36	350	2290	1075
	N	0.7	400	1750	14	530	335	610
Whole lake	A	8.5	2310	5570	63	700	3210	1465
	N	4.1	655	2680	30	810	1380	1470

Nutrient Elements

Area	Org-C	N	P
Weatern Basin	43200	5600	670
	41000	3600	1910
Central Basin	211300	29200	3450
	100300	11300	7660
Eastern Basin	302800	45000	9270
	207000	24900	12360
Whole lake	557300	79800	13390
	348300	39800	21930

* Anthropogenic loading

** Natural loading

Thus, the total loading of mercury to the lake is 12.6 metric tons/yr.

A discussion of the calculations can be best made by directly quoting the authors (25):

> "As with the total sediment budget, anthropogenic loadings of the heavy metals and nutrients are greatest in the eastern basin.. Although the major source areas for the anthropogenic materials are Detroit, Toledo and Cleveland, the eastern basin of the lake is acting as the major sink.
>
> Comparison of our results with other estimates of Hg, N and P inputs indicate that our values are of the right order of magnitude. The major Hg sources at Wyandotte, Michigan (4.5 to 9.1 kg/day) and Sarnia, Ontario (26.4 kg/day) are estimated to have released 3.3 and 9.6 metric tons respectively during 1970... The Hg distribution in the surface sediments of the Great Lakes demonstrates the downstream movement of Hg from the source areas...Thus our estimate of 8.5 metric tons of Hg in 1970....appears reasonable.
>
> A materials balance for the lake, based on 1966-1967 data, shows that 99,000 metric tons of N and 23,000 metric tons of P are retained within the lake (I.J.C. Report, 1969). Our estimates of 119,600 tons of N and 35,320 tons of P are again of the right order of magnitude. Estimates of 28,119 metric tons (Burns, this volume) and 40,000 metric tons (Williams, this volume) are closer to our own estimate for total P. It is not certain from the results that our breakdown into anthropogenic and natural P loading is correct."

A comparison of present-day (1935-present) and early-colonial (1850-1935) loadings was made in the earlier analysis of Lake Erie sediment

cores (3). Averaging values from five cores, the ratio of present-day to early colonial inputs was found to be 6.0 for organic carbon, 8.2 for N, 4.5 for P, and 8.0 for Hg. Looking back at Table 1.10, it is evident that if the natural loading remained constant over the time represented by the cores, it would be impossible to obtain ratios higher than 1.6 for OC; 2. for N; 0.6 for P; and 2.1 for Hg. This is an apparent conflict which needs to be resolved.

Historical Trends in Water Discharges in the Lake Erie Basin

The physical changes which have been experienced by the Lake Erie Basin since early Colonial times have had an impact on water discharges into the Lake. Two major changes have occurred: the early deforestation of the watershed, and the relatively recent growth in urban area. The time variation in both precipitation and runoff were analyzed in order to discover any possible trends from those physical changes.

Precipitation Trends

In order to uncover any long-term linear trends in precipitation over the lake the precipitation from 1860 through 1958 was subjected to a least squares analysis. The annual precipitation data has been tabulated in Powers, et al (26). The regression resulted in a value of $R^2 = 0.0000075$, so close to zero that no linear correlation between time and precipitation can be proven statistically. Average precipitation over the 96-year period was 34"/yr. It must be concluded that over the period of time which was analyzed, the precipitation regime over the lake did not change significantly with time.

In an attempt to look at the precipitation regime before 1860, the average annual precipitation at the Woodward High School, Cincinnati,

Ohio, was obtained (30). Precipitation was measured there between 1835 and 1902 without a break in the record. The periods 1860-1867 and 1871-1902, for which intervals both the Woodward records and the Lake Erie records coincide, were correlated. A correlation coefficient, R^2, of 0.0825 between the Lake Erie precipitation data and the Woodward data indicates little correlation between the two sets of records. Therefore, the Woodward record was not further examined for a possible long term trend.

The Woodward High School data may adequately represent the general climatic conditions in the Lake Erie-Southern Ohio region, considering less precise correlations, such as a comparison of periods having above and below average precipitation. These comparisons may help to explain lake level trends, which are discussed in section 1.8.3.

Runoff Trends

In order to study trends in runoff, it was necessary to look at long-term records. There are only two gaging stations in the Lake Erie Basin which have comparatively long record periods: the Huron River, Ann Arbor, Michigan, dating back to February, 1904, and the Auglaize River, Defiance, Ohio, with a record to April, 1915. Monthly runoff data was gathered for the latter station, which is a tributary to the Maumee River, for as many years as possible. About 5 years of record in the 1930's were not available and have not been included. In addition, monthly precipitation and temperature data was obtained for five stations in the watershed and averaged. This data was analyzed by a water budget approach to determine any time trends in water discharge over the period 1915-1973.

Water Budget

Assuming that the geographical boundaries of the groundwater reservoir coincide with the watershed surface, the equation for the water budget can be written as:

$$\frac{dS}{dt} = P - ET - G - Q - L \qquad \ldots[1.19]$$

with S = volume of water stored in basin, both above ground and underground, P = precipitation, ET = evapotranspiration, G = groundwater outflow, Q = surface runoff, L = use and other miscellaneous losses. It is assumed that over the period of a month the change in surface storage is negligible, an assumption which will not be true for months with snowfall but little snowmelt, and vice-versa, and for months in which large runoff events occur late in the month. However, continuing with that assumption,

$$\frac{dS}{dt} = n\,\frac{dV}{dt} = I - G \qquad \ldots[1.20]$$

in which n = porosity, V = volume of saturated zone, I = infiltration. Combining the two equations

$$P - ET - I - Q = L \qquad \ldots[1.21]$$

The data available yields values of P and Q. Through the monthly temperature data it is possible to estimate ET, although daily data is far superior for this purpose. Infiltration and loss are the remainder from the analysis, and it is expected that these terms depend on precipitation, population and character of the watershed surface.

However, exhaustive computer analyses of runoff failed to show any

trends. For example, the regression of one defined runoff coefficient (P - R)/P, resulted in an upward trend of 0.007% per year, but with a value of $R^2 = 0.014$. This low value of R^2 fails to demonstrate any significant correlation between the runoff and time. When the evapotranspiration was estimated, so that the runoff coefficient was given by (P - R - ET)/P, the correlation was reduced to 0.00029.

The conclusion that runoff in the Auglaize River Watershed has not changed relative to precipitation signifies that the watershed response has remained constant since 1915. Since it is an almost completely agricultural watershed it is expected that only a relatively minor change should have occured in runoff over the past years, if any. Even a relatively large increase in urban area would not have much effect on the total runoff from such a large basin. Therefore, the results of this analysis should not be interpreted as applying to urbanizing areas of the Lake Erie Basin.

It is possible that the runoff coefficient at Independence on the Cuyahoga River may have increased during this century. In 1905 its value was 0.37, about the same as the long-term value for the agricultural watersheds at Coshocton, Ohio. The early runoff data is scanty and it is difficult to be precise about that value. It appears that the current value may be near 0.6, implying a change of about 0.7%/year. One effect in the Cuyahoga River Basin is evident: since the construction of the Akron Sewage Treatment Plant in the 1920's the runoff coefficient at Old Portage, just above the treatment plant, has dropped to one-half of the value of the runoff coefficient of the subbasin below the plant. This is solely due to Water use in Akron and sub-

sequent bypassing of wastewater around the section of river which includes the treatment plant. This phenomenon illustrates the difficulty of making generalizations about runoff characteristics. Each situation must be individually studied.

Lake Level Changes

In Figure 1.5 are plotted data on the levels of Lake Erie since 1800. The data for pre-1860 levels was obtained and interpreted by Powers, et al (26). The solid line between 1865 and 1955 is copied from Brunk (27), applying 1.94 feet as a downward shift to his curve, and represents a 10-year moving average of annual values. The pre-1860 levels have also been shifted so that they agree with the new datum of the National Ocean Survey (black circles) (28).

A notable trend of the figure is the dramatic rise of lake level from the beginning of the 19th century up to about 1840. The level in 1796 was apparently near the lowest of recorded history. The cause of this trend is unknown. Powers, et al (26), suggest the possibility that the presence of the forest increased water loss through transpiration, interception, and retention, thereby maintaining a lower lake level regime than at present.

On the other hand, Brunk reported an earlier analysis "that cultural changes in the Lake Erie Basin had probably caused a *progressive* increase in water losses and a corresponding *reduction* on runoff." (29)

Records of precipitation in Ohio do not go back much farther than 1860 in most locations. At Cincinnati, temperature records have been maintained since 1792. Until 1835 monitoring was spotty, but continuous records have been maintained ever since, starting with the Woodward

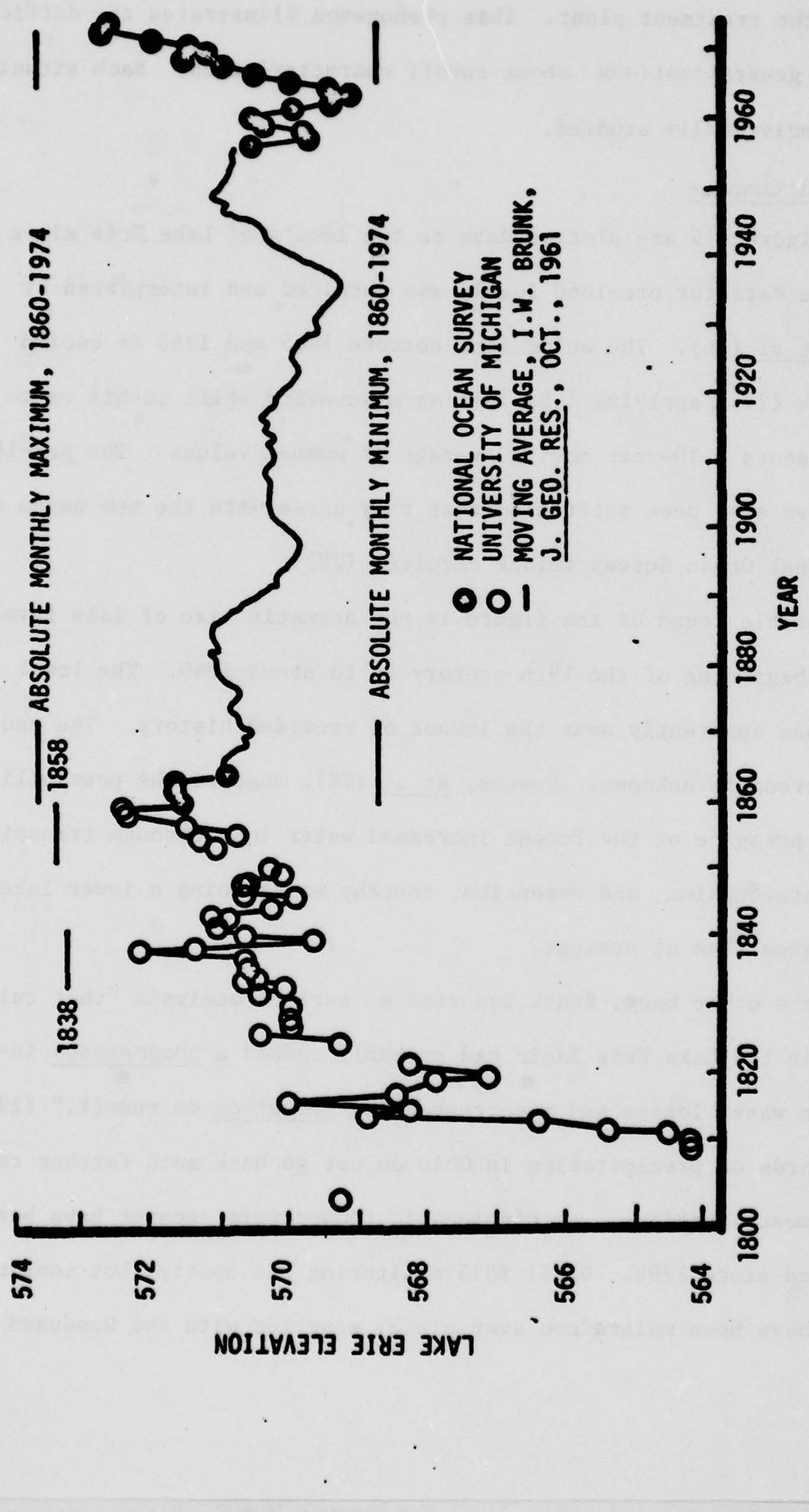

Fig. 1-5 LAKE ERIE WATER LEVELS

High School gage (30). Analyzing that record, it is seen that the period 1835-1855 was one of almost consistently above-average precipitation. Only 3 of the 21 years had below-average precipitation. 1856-1875 had 13 of 20 years in the same category. 1876-1895 yielded 14 of 20 years with below-average rainfall. 1896-1915 had 11 of 20 years below-average.

It appears that high rainfalls in the years about 1830-1855 caused the high lake levels of that period. Lower precipitation, ending in the late 1930's sent levels down again. Whether the pre-1830 era was one of exceptionally low precipitation is a question of considerable historical interest.

Without making a detailed analysis of the water budget of the lake, it appears that the early deforestation of the watershed and the change to agricultural conditions did not substantially change the runoff conditions in the watershed. Only a careful analysis can supply a sufficiently precise answer, of course.

Total Surface Runoff into Lake Erie

The average annual runoff into Lake Erie was calculated. The total ~~surface~~ runoff is considered to be the sum of the ~~surface~~ runoffs of all the watershed areas located in the Lake Erie Basin. These watershed areas were identified on maps supplied to us by the Army Corps of Engineers, Buffalo District. In this portion of the study, each watershed area was identified by the name of the river draining that area. If no major tributary drains a watershed, the area was identified as "unnamed". A further distinction was that named basins have usually been monitored for discharge, and unnamed watersheds either have not been measured, or

the records were not generally available. Two values for total ~~surface~~ runoff were obtained. One was found using all available discharge data since 1950 and a second was found using data from the interval 1963 to 1972.

The method used to determine the discharge of each named watershed was as follows. First, yearly data for all relevant measuring stations located within the watershed area was tabulated and the average for the time interval was calculated for each measuring station. An example is Table 1.11 . Annual flow data for watersheds located in the U.S. was obtained from U.S. Geological Survey publications. For Canada, discharge data was obtained from publications of the Water Survey of Canada, Inland Waters Branch, Department of Energy, Mines, and Resources, Ottawa, Canada. Second, the average flow at each measuring station was plotted against the drainage area attributed to that measuring station. Third, a best fitting straight line was visually fitted to the graph. The second and third stages are illustrated in Figure 1.6 which applies to the Maumee River Basin.Fourth an average daily discharge corresponding to the total area of the watershed at the Lake shore was extrapolated from the graph. A yield was then attributed to the entire watershed by dividing the discharge by the area. When only one measuring station was located within the watershed area, its yield was determined and this yield was assigned to the total watershed area. Then the total watershed average daily discharge was found by multiplying the total watershed area by the yield of the measuring station. This method gave accurate results even for watersheds with one gaging station because the solitary station typically was located downstream far enough to include most of the drainage area of the ....

Table 1.11 MAUMEE RIVER RUNOFF DATA
(Ohio, Indiana, Michigan)

At Lake Erie: Estimated Mean Discharge = 5150 cfs

Watershed Area = 6608 mi^2

Station#	1805	1830	1835	1850	1915	1925	1935	1820
Area	1060	1940	2049	441	2329	5530	6314	762
1950								
1951	1480		2943	561	2961	7448	8587	990
1952	1245		2452	452	2426	6118	7016	827
1953	396		927	112	806	1975	2302	379
1954	610		985	180	560	1878	2270	210
1955	894		1834	257	1889	4376	4899	635
1956			1856	346	1765	4418	5266	543
1957		1515	1607	172	1887	3991	4547	770
1958		1802	1818	319	1892	4510	5293	838
1959		2081	2126	367	2429	5419	6452	889
1960		1734	1761	407	1431	4023	5160	466
1961		1342	1388	231	1374	3312	3930	534
1962		1206	1260	236	1090	2874	3407	492
1963		669	711	95	763	1709	1996	277
1964		858	886	60	1296	2447	2733	443
1965		1289	1325	212	1261	3163	3594	391
1966		1040	1052	259	970	2600	3323	
1967		1792	1949	337	2499	5180	6371	
1968		2197	2342	461	2118	5639	6297	
1969								
1970		1491	1647	143	1949	4184	4894	
1971		1116	1267	269	1199	3108	3620	
1972		1625	1697	214	1929	4450	5065	
1973								
1974								
TOTAL MEAN	925	1450	1611	271	1643	3944	4620	579
TMD/AREA								

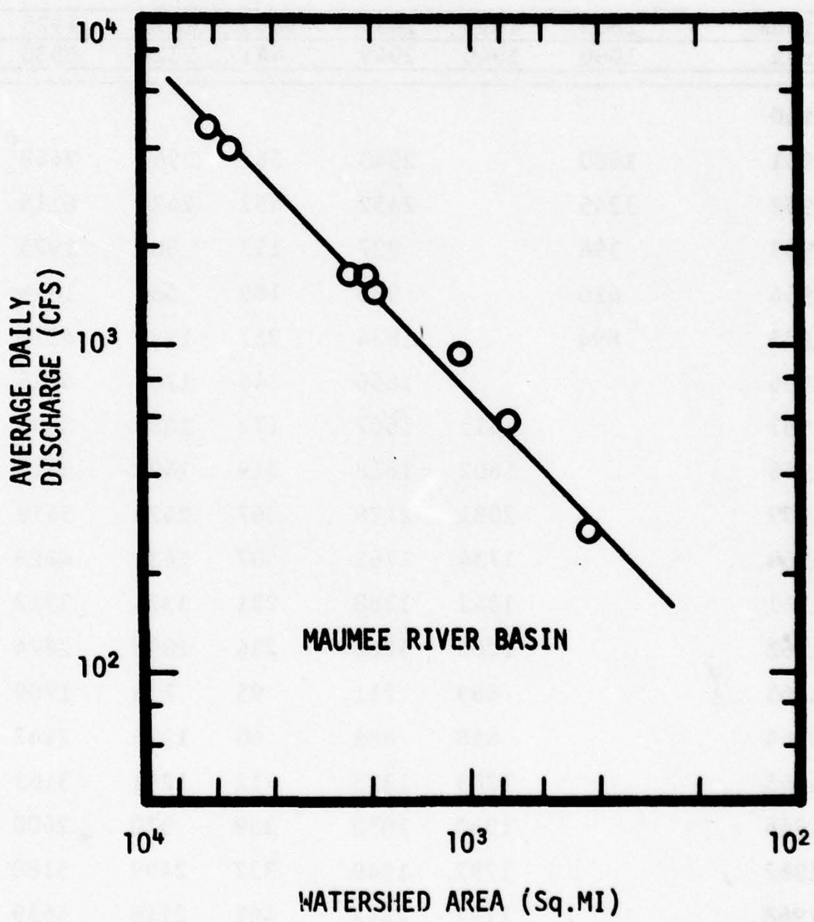

Fig. 1-6 RUNOFF AS A FUNCTION OF WATERSHED AREA, MAUMEE RIVER BASIN

watershed. Furthermore, it was discovered that the water discharge in a basin generally increases in the downstream direction proportionally with the watershed area.

In order to find the average daily runoff for unnamed watersheds, the following method was used. First, each watershed was given a rating corresponding to its distance from the mouth of the Huron River measured in a counter-clockwise direction along the shoreline of Lake Erie. This measurement was made either to the mouth of a major tributary or, alternatively, to the center of the unnamed basin along the shoreline. Second, the yield for each named watershed was plotted as a function of its shoreline distance as in Figure 1.7 or Figure 1.8 . Third, a best fitting curve was visually fitted to the graph just described. Fourth, yields for unnamed watersheds were interpolated from the curve developed in the previous step. The discharge for each unnamed watershed was then obtained by multiplying its yield by its area.

The average daily inflow to Lake Erie for the extended period was found to be 20,451 cfs. For the 10-year interval, 1963-1972, it was found to be 18,908 cfs. All results for watershed areas are displayed in Table 1.12. In 1968, the U. S. Department of the Interior published a report in which it found total surface runoff to be 20,331 cfs (31). A breakdown of this amount is shown in Table 1.13. The difference between their estimate and this estimate for the extended period is only 6/10 of one percent. Water inputs as calculated by Herdendorf (17) yield a value of 19,978 cfs for the extended period, also in close agreement.

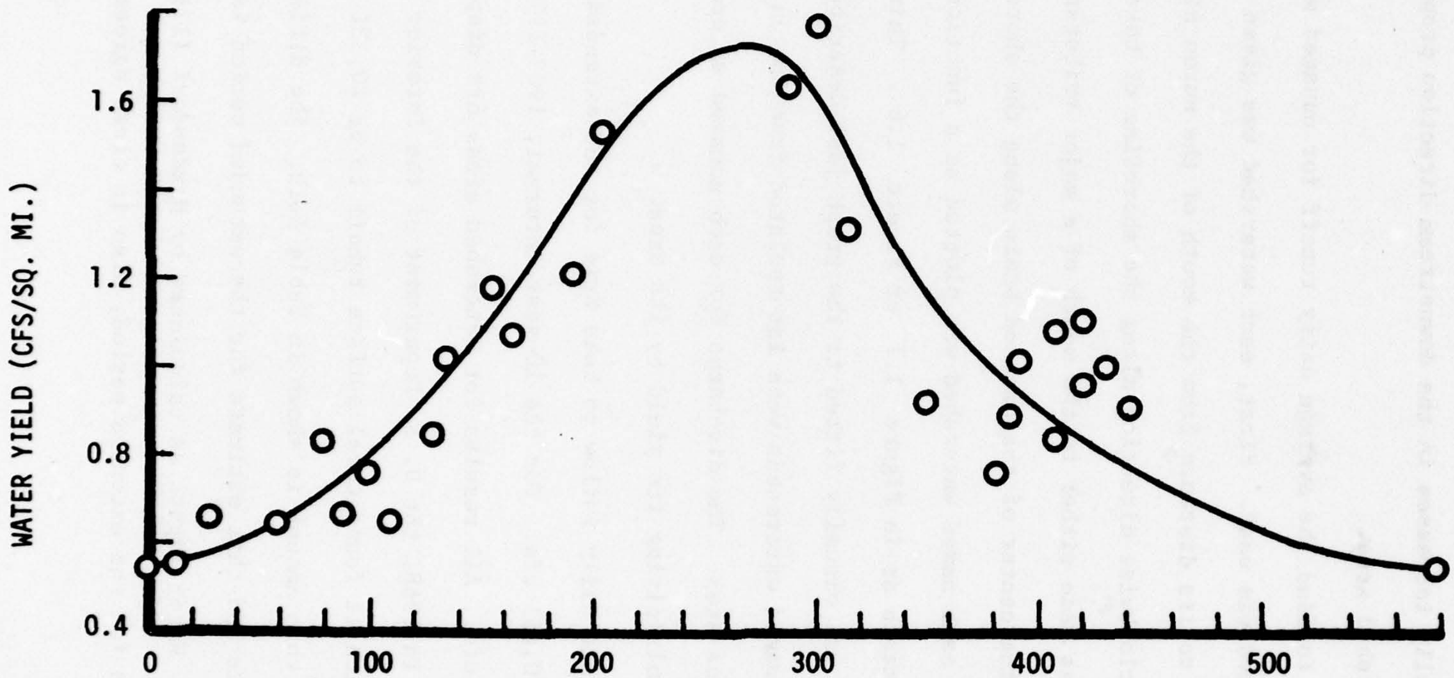

Fig. 1-7 VARIATION OF WATER YIELD AROUND LAKE ERIE, 1963-1972

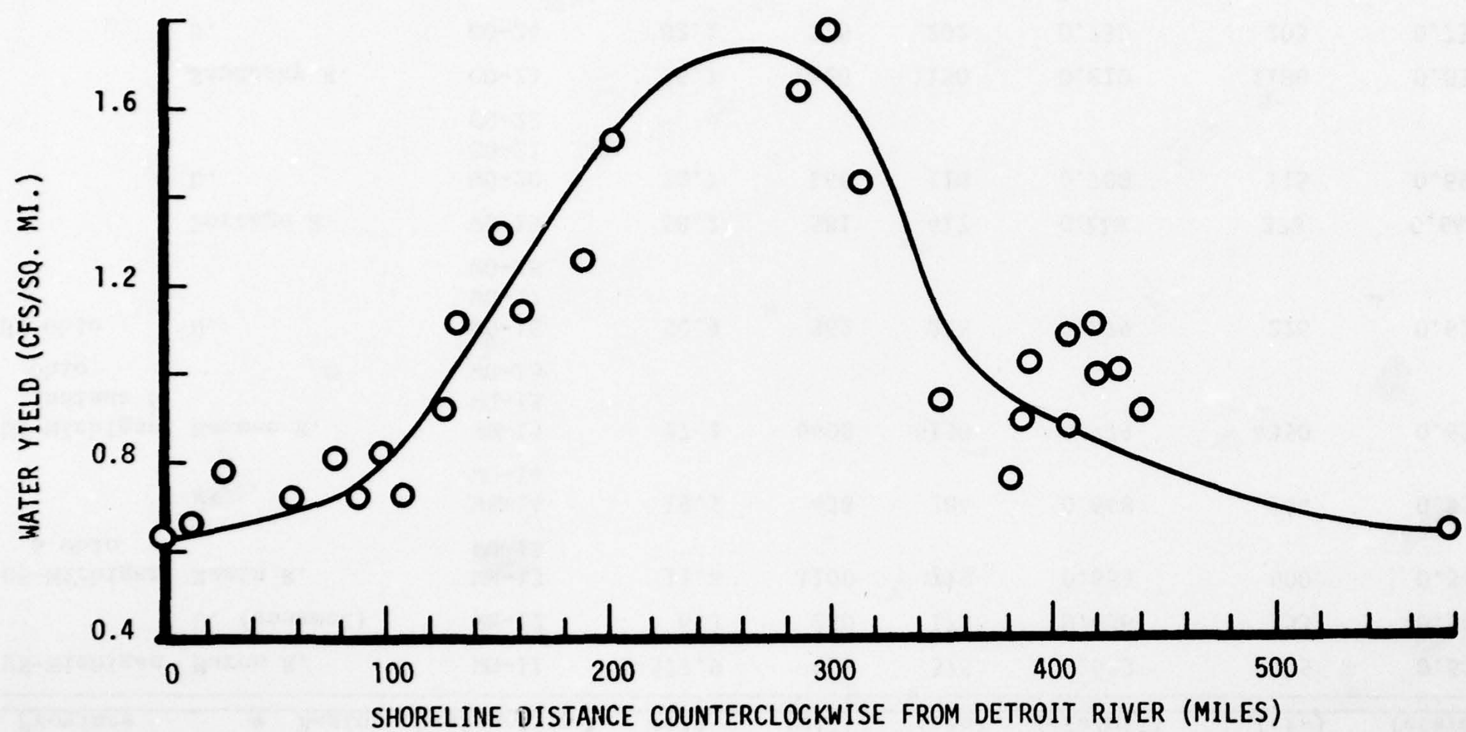

Fig. 1-8 VARIATION OF WATER YIELD AROUND LAKE ERIE, 1950-1972

Table 1.12 TRIBUTARY RUNOFF INTO LAKE ERIE

Country and State Or Province	River Basin	Land Mass Designation[1]	Distance (mi)	Total Drainage Area (mi^2)	For All Available Data Since 1950		Available Data For 10-Year Period 1963-1972	
					Discharge* (cfs)	Yield (cfs/mi^2)	Discharge* (cfs)	Yield (cfs/mi^2)
US-Michigan	Huron R.	WM-11	0-577.9	908	575	0.633	495	0.545
	U. (unnamed)	WM-12	6.3	280	178	0.636	153	0.547
US-Michigan & Ohio	Rasin R.	WM-13 WO-13	11.8	1100	719	0.654	600	0.545
	U.	WM-14 WO-14	19.5	438	284	0.648	244	0.558
US-Michigan, Indiana & Ohio	Maumee R.	WM-15 WI-15 WO-15	27.2	6608	5150	0.779	4350	0.658
US-Ohio	U.	WO-16 WO-17 WO-18	50.9	362	246	0.679	226	0.624
	Portage R.	WO-19	58.2	581	417	0.718	373	0.642
	U.	WO-20 CO-21 CO-22	70.7	166	118	0.708	115	0.692
	Sandusky R.	CO-23	76.7	1420	1150	0.810	1180	0.831
	U.	CO-24	82.1	275	202	0.733	203	0.737
	Huron R.	CO-25	87.5	406	293	0.722	269	0.663
	U.	CO-26	92.7	83	64	0.770	65	0.782
	Vermillion R.	CO-27	97.9	268	219	0.817	202	0.754
	U.	CO-28	103.0	72	59	0.822	60	0.827

* Average Daily Discharge

Table 1.12 (continued)

Country and State or Province	River Basin	Land Mass Designation[1]	Distance (mi)	Total Drainage Area (mi^2)	For All Available Data Since 1950		Available Data For 10-Year Period 1963-1972	
					Discharge* (cfs)	Yield (cfs/mi^2)	Discharge* (cfs)	Yield (cfs/mi^2)
US-Ohio (contd)	Black R.	CO-29	108.2	470	341	0.726	303	0.645
	U.	CO-30	117.4	51	46	0.902	46	0.902
US-Ohio	Rocky R.	CO-31	126.6	293	269	0.918	248	0.846
	Cuyahoga R.	CO-33	133.2	809	900	1.112	820	1.014
	U.	CO-34	142.5	90	98	1.092	94	1.039
	Chagrin R.	CO-35	151.8	264	347	1.315	310	1.174
	U.	CO-36	156.8	29	35	1.207	33	1.134
	Grand R.	CO-37	161.8	705	800	1.135	755	1.071
	U.	CO-38	175.2	115	155	1.345	145	1.262
Us-Ohio & Penn.	Ashtabula R.	CO-39 CP-39	188.6	137	172	1.253	165	1.204
	Conneaut Ck.	CO-41 CP-41	202.2	189	287	1.519	288	1.524
US-Penn	U.		224.4	333	547	1.644	537	1.613
US-N.Y.	U.	EN-46 EN-47 EN-48	266.2	287	494	1.722	494	1.722
	Cattaraugus Ck.	EN-49	285.8	552	900	1.630	900	1.630
	Eighteen Mile Ck	EN-50 EN-51 En-52	299.3	280	494	1.765	494	1.765

* Average Daily Discharge

Table 1.12 (continued)

Country and State or Province	River Basin	Land Mass Designation[1]	Distance (mi)	Total Drainage Area (mi^2)	For All Available Data Since 1950 Discharge* (cfs)	For All Available Data Since 1950 Yield (cfs/mi^2)	Available Data For 10-Year Period 1963-1972 Discharge* (cfs)	Available Data For 10-Year Period 1963-1972 Yield (cfs/mi^2)
US-N.Y. (contd)	Buffalo R.	EN-53	313.0	433	616	1.422	567	1.309
Canada Ontario	U.	2HA-9	331.1	57	78	1.370	74	1.303
	Grand R.	2GA 2GB	349.2	2620	2450	0.935	2410	0.920
	U.	2GC-10, 13,12	365.5	148	148	1.000	157	1.058
	Nanticoke Ck.	2GC-11	381.8	95	72	0.758	72	0.758
	Lynn R.	2GC-9	386.8	99	88	0.884	88	0.884
	Young Ck	2GC-7 (Part)	390.0	64	65	1.017	65	1.017
	Dedrich Ck.	2GC-7 (Part)	406.7	56	60	1.075	60	1.075
	Big Ck.	2GC-8	407.2	270	235	0.870	225	0.833
	U.	2GC-6, 5(Part)	413.2	62	53	0.851	54	0.869
	South Otter Ck.	2GC-5 (Part)	419.2	44	48	1.102	48	1.102
	Big Otter Ck.	2GC-4	419.9	311	308	0.991	298	0.958
	Catfish Ck.	2GC-3	430.3	153	153	1.000	153	1.000
	Kettle Ck.	2GC-2	440.9	183	165	0.904	165	0.904

* Average Daily Discharge

Table 1.12 (continued)

Country and State or Province	River Basin	Land Mass Designation[1]	Distance (mi)	Total Drainage Area (mi^2)	For All Available Data Since 1950		Available Data For 10-Year Period 1963-1972	
					Discharge* (cfs)	Yield (cfs/mi^2)	Discharge* (cfs)	Yield (cfs/mi^2)
Canada-Ontario (contd)	U.	2GF	478.4	293	210	0.717	203	0.692
	U.	2GH-6, 7, 8, 9	546.9	224	143	0.639	128	0.571

[1]Two land mass designation systems are listed here for the convenience of those using this report. For watersheds located in the U.S., a system in current use by the Army Corps of Engineers, Buffalo District is listed. This designation indicates the state, discharge location, and land mass number. A case in point, WM-13 indicates: 1.) W - discharge is into the Western Basin of Lake Erie, 2.) M - Land area is in Michigan, and 3) 15 - Land mass number. For drainage basins located in Canada, the designation in current use by the Water Survey of Canada is listed.

* Average Daily Discharge

Table I-13

WATER SUPPLY TO LAKE ERIE

Source: Lake Erie Environmental Summary, 1963-1964
U.S. Department of the Interior
Federal Water Pollution Control Administration,
Great Lakes Region
May, 1968

	Source	Supply (cfs)	Percent of Total Lake Supply	Percent of Basin Supply
	Western Basin			
	St. Clair River (Lake Huron, outflow)	187,450	79.774	92.921
	Black, Pine, Belle Rivers	688	.293	.338
	Clinton River	470	.200	.231
	Rouge River	235	.100	.115
	Thames River	1,840	.783	.903
	Miscellaneous Runoff	1,799	.766	.883
	Precipitation (Lake St. Clair)	919	.391	.451
	Subtotal (Detroit River	193,401	82.307	94.943
	Huron River (Michigan)	556	.237	.273
	Raisin River	714	.304	.351
A	Maumee River	4,794	2.040	2.353
	Portage River	403	.172	.198
	Miscellaneous Runoff	1,271	.541	.624
	Precipitation (Western Basin)	2,564	1.091	1.259
	Subtotal	10,302	4.384	5.057
	Total Western Basin	203,703	86.691	100.000
	Evaporation	-3,042	-1.295	-1.493
	Central Basin			
	Western Basin	200,661	85.396	90.966
	Sandusky River	1,021	.435	.463
	Huron River (Ohio)	296	.126	.134
	Vermilion River	228	.097	.103
	Black River	302	.129	.137
	Rocky River	273	.116	.124
	Cuyahoga River	850	.362	.385
B	Chagrin River	333	.142	.151
	Grand River (Ohio)	784	.334	.355
	Ashtabula River	169	.072	.077
	Conneaut Creek	257	.109	.117
	Otter Creek	312	.133	.141
	Kettle Creek	185	.079	.084
	Miscellaneous Runoff	1,410	.600	.639
	Precipitation (Central Basin)	13,508	5.749	6.124
	Total Central Basin	220,589	93.877	100.000
	Evaporation	-16,023	-6.819	-7.264

Table 1-13 (continued)

Source	Supply (cfs)	Percent of Total Lake Supply	Percent of Basin Supply
Eastern Basin			
Central Basin	204,566	87.058	94.746
Cattaraugus Creek	705	.300	.327
Buffalo River	784	.334	.363
C Grand River (Ontario)	2,405	1.024	1.114
Big Creek	256	.108	.119
Miscellaneous Runoff	2,023	.861	.937
Precipitation (Eastern Basin)	5,172	2.201	2.395
Total Eastern Basin	215,911	91.886	100.000
Evaporation	-6,135	-2.611	-2.841
Lake Outflow	209,776	89.275	

Sum for A	7,738 cfs
Sum for B	6,420
Sum for C	6,173
Total Runoff	20,331 cfs

CULTURAL TRENDS IN THE LAKE ERIE BASIN

Through the ages human civilization has profoundly and systematically altered its immediate environment in response to needs, purposes, and desires. In the process adjacent regions have been affected, resulting in a complex web of impacts which at times have been difficult or impossible to isolate and analyze. This has been graphically displayed in other sections of this report. Of no slight concern are the possible relationships between human activities and declines in the qualities and quantities of natural resources. In order to implement programs which can deal effectively with specific environmental and resource problems, we must have information on cultural impacts on water resources and on trends in population and resource usage.

Phosphorus Sources Into Surface Waters

Phosphorus may appear in water and sediment in either organic or inorganic form and as soluble or insoluble. The organic phosphorus matter comes exclusively from dead plants and organisms. The process of luxury uptake, which is a recycling of the excess organic phosphorus stored in dead organisms in lakes, contributes to the problem of accounting for total phosphorus. Outside of leaves, pollen and other organic material washed away by surface drainage, most of the phosphorus which enters Lake Erie is insoluble and inorganic. Major contributors are

surface drainage from agricultural sources and domestic wastes, including detergents. Phosphorus also comes from industrial processes and uses, rainfall, ground water seepage, runoff from undeveloped land and urban areas, and farm and urban animal wastes. Figure 2-1 diagrams the relationship of these sources.

Precipitation

The direct contribution of phosphorus from rainfall and snow onto the surface of water bodies may be substantial. Murphy estimates that between 1/5 and 1/3 of Lake Michigan's phosphorus intake is from precipitation (41). Using an average concentration of 0.1 mg/ℓ and the figure of 34"/year of rainfall onto Lake Erie, the net result would be 2,500 tons/year of phosphorus inflow from precipitation. The concentration of phosphorus in precipitation depends on the amount of airborne phosphorus which is entirely present as particulate matter. The bulk of airborne phosphorus is probably from industrial processes. In Table 2.1 are displayed some of the measured concentrations of phosphorous in precipitation.

Table 2.1. Phosphorous Concentrations in Rainfall

Source	Concentration (mg/ℓ)	Location
Tamm (39)	0.03	Bogesund, Sweden
Voight (39)	0.01	Southern Connecticut
Weibel *et al* (40)	0.08	Cincinnati (Urban)
	0.003	Coshocton (Rural)
Murphy (41)	0.34	Chicago (1974)

Groundwater

Almost all phosphorus which enters the groundwater is in a soluble form. This is a result of the weathering of natural deposits and the

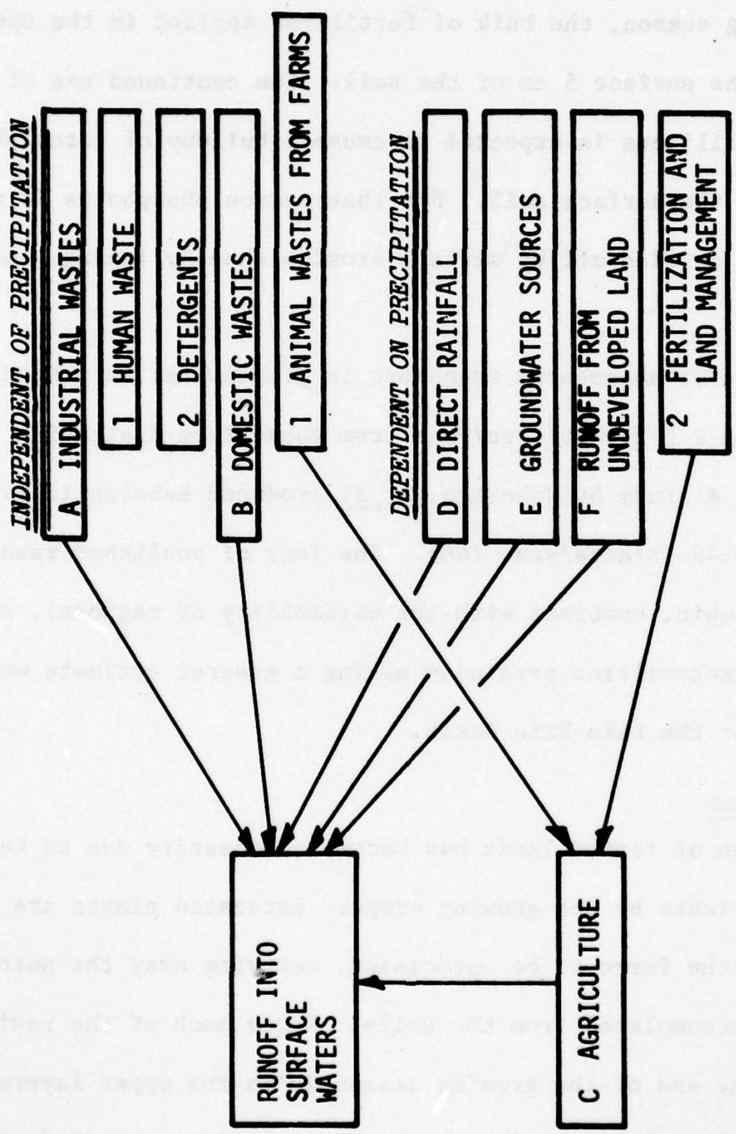

Fig. 2-1 PHOSPHORUS SOURCES INTO SURFACE WATERS

leaching of applied soluble fertilizers. In general, however, phosphorus bearing compounds react vigorously with the soil and most is absorbed and fixed. Experiments by Black, for example, show that at the end of the normal growing season, the bulk of fertilizer applied in the spring has remained in the surface 5 cm of the soil. The continued use of phosphates as fertilizers is expected to cause a buildup of total phosphorus content in the surface soil. For that reason phosphorus is much more likely to be carried off by surface erosion than by leakage into groundwater.

Few estimates of phosphorus transport in groundwater have been made. Sylvester reported 2.5-8.9 lb/acre/year from subsurface drains in Washington (35). A study by Johnston, et al produced substantially lower figures of 0.02-0.48 lb/acre/year (48). The lack of published research results on this topic, combined with the variability of regional, physical and geologic characteristics precludes making a general estimate which would be valid for the Lake Erie Basin.

Fertilized Farmland

Fertilization of farmed lands has become a necessity due to the depletion of nutrients by the growing crops. Harvested plants are transported away from the farms to be processed, carrying away the nutrients which they have accumulated from the soils. Since much of the residual phosphorous at the end of the growing season is in the upper layers of the soil and easily subject to loss by surface erosion, runoff from farm lands is a major contributor of phosphate runoff and pollution in this nation.

A survey of phosphorus contribution in runoff from fertilized farm-

lands appears in Table [2.2]. The range of most of these estimates and measurements is between 0.3 and 5 lb/acre-year. The particular yields correspond to the amount and type of precipitation, climate, soil type, slope of land, fertilizer application and land management practices, and there is presently insufficient data available to formulate functional relationships.

As an example Table [2.3] gives the results of two research studies. They suggest relationships between phosphorus yield and other variables, particularly the crop grown, but more detailed research is required before relationships can be developed which are transferable between watersheds.

Domestic Waste

Domestic use and disposal of phosphorus almost exclusively involves human wastes and washing products. Except for septic tanks and the possibility of direct discharge, either in combined sewer overflows or direct disposal, all of this phosphorus enters the municipal treatment plant. Estimates of phosphorus amounts in human waste are tabulated below.

Table 2.4 PHOSPHORUS FROM DOMESTIC WASTES

Source	Amount (Lb-P/Capita-yr)	Location
Vollenweider (42)	1.75	
Porcella, *et al* (43)	2.2	Suburban Utah
Sherman (44)	2.3 Maximum 0.5 Minimum 1.3 Mean	Varied in U.S.
Hawk *et al* (45)	1.4	

Table 2.2

ESTIMATES OF PHOSPHORUS RUNOFF
FROM FERTILIZED FARMLAND

Source	Yield lb/acre/yr.	Location
Webber and Elrick	0.003 to 1.0	
Sawyer (46)	0.4	Madison, Wisc.
Sylvester (35)	0.9-3.9	Washington
Englebrecht and Morgan (56,71)	0-15 (Mean = 0.35)	Illinois
Burwell, et al (36)	0.631	
Grandina (70)	0.5-5	Latvia
Harms, et al (36)	(Mean = 0.3)	South Dakota

Table 2.3 SOME VARIABLES AFFECTING PHOSPHORUS IN FERTILIZED LAND RUNOFF

Source	Crop	Applied Phosphorus Fertilizer (Lbs/Acre-Yr)	Size of Fertilized Area (Acres)	Other Land Management Techniques	Snow (in./yr)	Rain (in./yr)	Total Phosphorus in Drainage (Lb/Yr-Acre)	Other
Harms et al (36)	1. Oats-Corn		7.18		23	23.26	.27	
	2. Oats-Corn		8.77		23	21.77	.27	
	3. Alfalfa-Brome Grass		10.12		23	22.79	.09	
	4. Alfalfa-Brome Grass		8.77		23	22.79	.09	
	7. Pasture		15.51		23	22.99	.22	
	8. Corn-Oats		18.68		23	23.02	.27	
	9. Corn-Oats		9.79		23	23.75	.27	
Burwell et al (38)	1. Variety Corn Soybeans	 25 0	322.4	Level-Terraced		27.2	.399	Runoff = 3.48 in.; Sediment Yield = .48 tons/yr-acre
	2. Corn	35	83	Contour Planted		29.9	.863	Runoff = 5.29 in.; Sediment Yield = 10.34 tons/acre-yr.

Since in 1970 the total population in the Lake Erie basin was approximately 11.6 million people, and assuming a waste discharge of 2.0 lb-P/capita/year, the domestic waste load generated in the basin would be on the order of 23 million pounds.

Detergents

In Table [2.5] are listed some figures for synthetic detergent production and per capita phosphate load from detergents.

Table 2.5.

ESTIMATES OF DETERGENT PHOSPHOROUS YIELDS

Source	Year	Production of Synthetic Detergents (Lbs x 10^6)	Per Capita Phosphate Contribution from Detergents (Lb/Capita-yr)
Bartsch (58)	1945	83	
	1950	1030	
Sawyer (55)	1950		1.6
Bartsch (58)	1955	2330	
Engelbrecht (56) & Morgan	1955		1.9
A.W.W.A. (57)	1958		2.1
Bartsch (58)	1960	3330	2.1
	1965	4160	2.6
	1968	4730	3.2 (est.)
EPA (27)	1970		2.6

Although the use of phosphates in detergents has increased every year up until about 1973, the current and future use depends largely on partial or full bans either in effect or being considered. One of these which has been reported in the literature was implemented in Erie County, N.Y. (49).

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HISTORICAL TRENDS IN POLLUTANT LOADINGS TO LAKE ERIE.(U)
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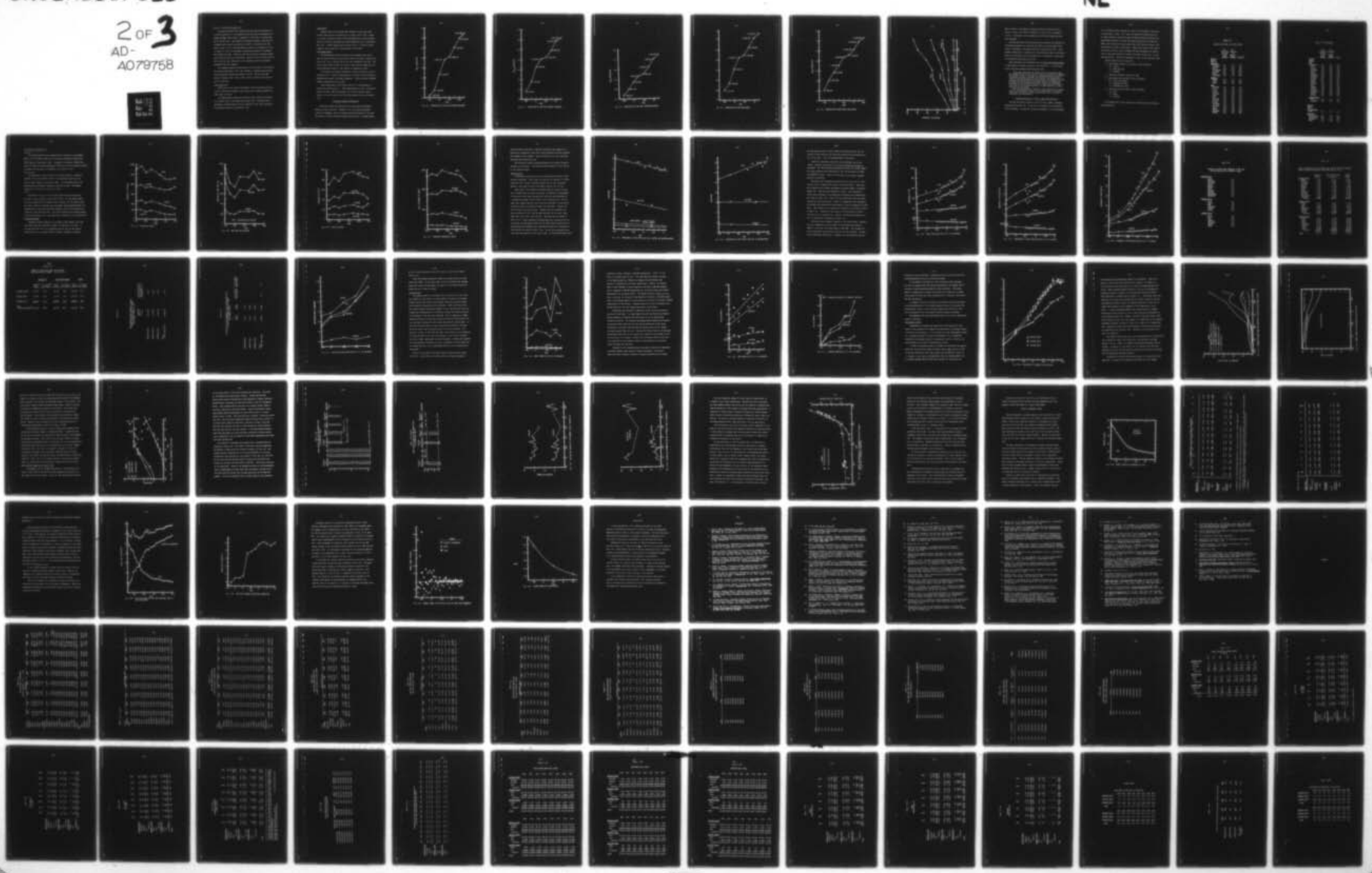

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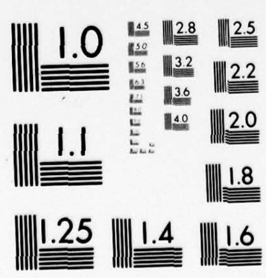

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Effect of Phosphate Detergent Ban

Pieczonka and Hopson have analyzed the Erie County phosphorus ban through measurements of the phosphorus load entering the Lackawanna, N.Y. Sewage Treatment Plant under 3 conditions: 1) full ban, 2) partial ban, and 3) pre-ban (49). The influent was primarily domestic waste and the treatment plant served a population of 28,657. The partial ban took effect on May 1, 1971, limiting phosphate content in detergents to 8.7%. On January 1, 1972, all detergents containing any amount of phosphates were banned from sale. During the partial ban period, detergents bought before May 1971 were still being used. However, after the first month or two of the full ban, almost all of the remaining stocks of phosphate detergents had been consumed.

The average phosphorus concentration of the influent in the pre-ban test period, March-April, 1971, was 7.45/mg/ℓ. During the partial ban period phosphorus content was reduced by 15.2%. The full-ban test period of January, 1972 - March, 1973, found a reduction of 66.2% over pre-ban conditions.

Undeveloped Land

While most of the research undertaken to date has dealt with artificially fertilized farmlands, some studies have yielded information on other rural land uses.

The FWQA measured phosphorus yields of from 0.034-0.18 lb/acre/yr. for forested land in the Potomac River Basin (33). Forested land in Washington yielded between 0.32-0.77 lb/acre/yr. (34), while pasture in South Dakota yielded 0.22 lb/acre/yr. (35).

Urban Runoff

Samples taken in 1959 showed that samples of storm water from Seattle street gutters contained up to 1.4 mg/ℓ total P (50). Weibel et al made an extensive study of the characteristics of water running off from a 27-acre residential and light commercial area in Cincinnati, Ohio (51). Yields ranging from less than 0.007 to 2.4 mg/ℓ of hydrolyzable P were found with a storm average of 0.37 mg/ℓ.

Farm Animal Wastes

The Environmental Protection Agency has estimated that cattle, poultry, pigs and sheep in the Lake Erie Basin contribute, respectively, about 1.0%, 1.5%, 1.0% and 0.5% of the total phosphorus load (52). Not only do farm animals produce ten times as much waste as humans but the total phosphorus content is also greater in magnitude as well.

The average cow produces 60 lbs/day of manure of which 0.1 lbs.is phosphorus (53). Typical characteristics of feedlot runoff in Eastern Nebraska were between 15-80 mg/ℓ phosphates. Yields from dirt surfaced feedlots averaged 165 lb/acre-year.

Other measurements have yielded figures for orthophosphate in agricultural land runoff as: .005/lb/day/animal for sows; .023 lb/day/animal for hogs; .008 lb/day/animal for 60 tons of poultry wastes spread on 15 acres yearly; and .006 lb/day/animal for beef in pasture (54).

Historical Trends in Population

Population trends are important due to associated anthropogenic impacts on water resources. Figures 2.2-2.7 and supporting Tables 2.6A-2.17A (Appendix) report increasing population figures for the Lake Erie Basin at 10-year intervals between 1890 and 1970. Although broken

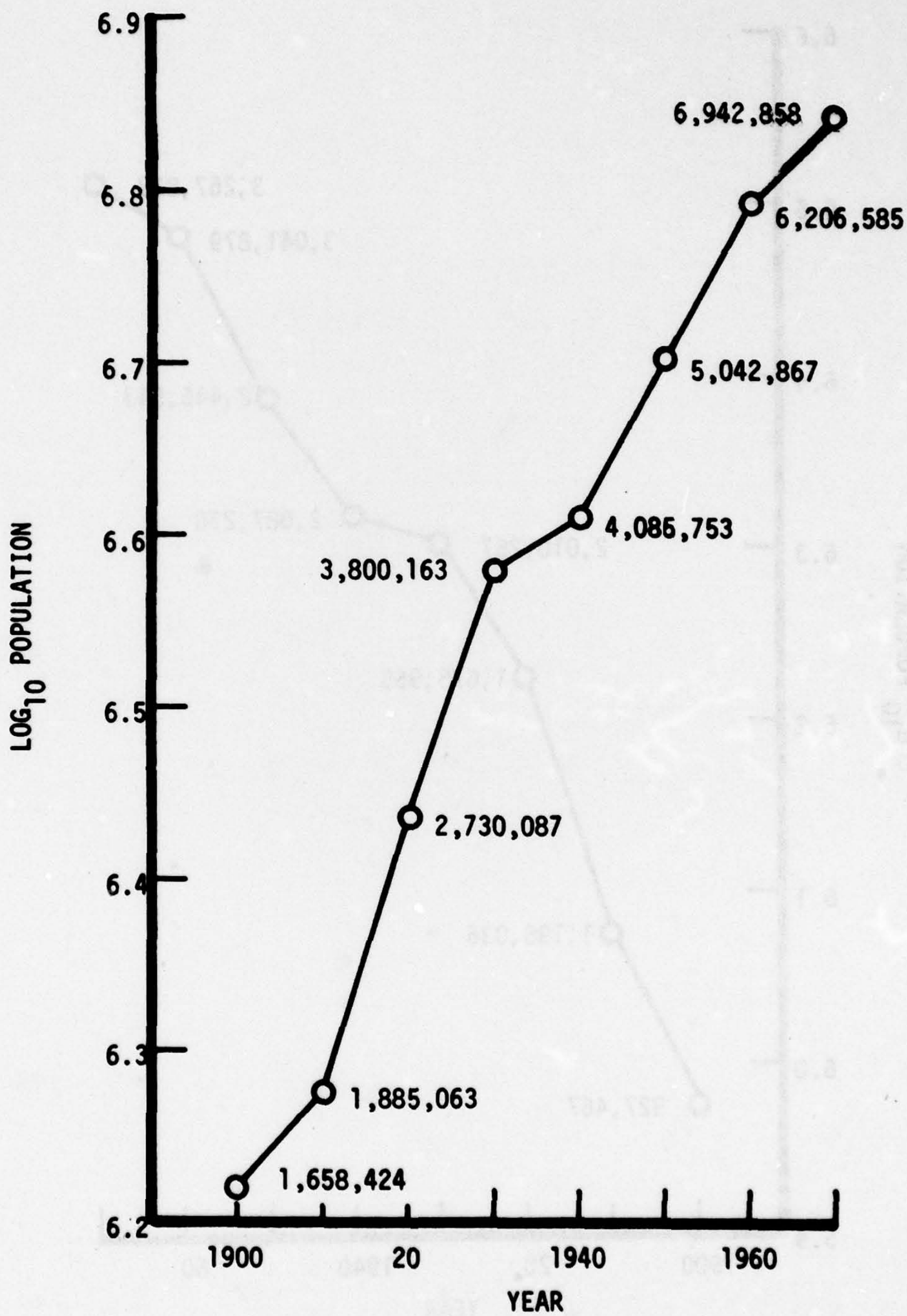

Fig. 2-2. POPULATION OF LAKE ERIE WESTERN SUB-BASIN

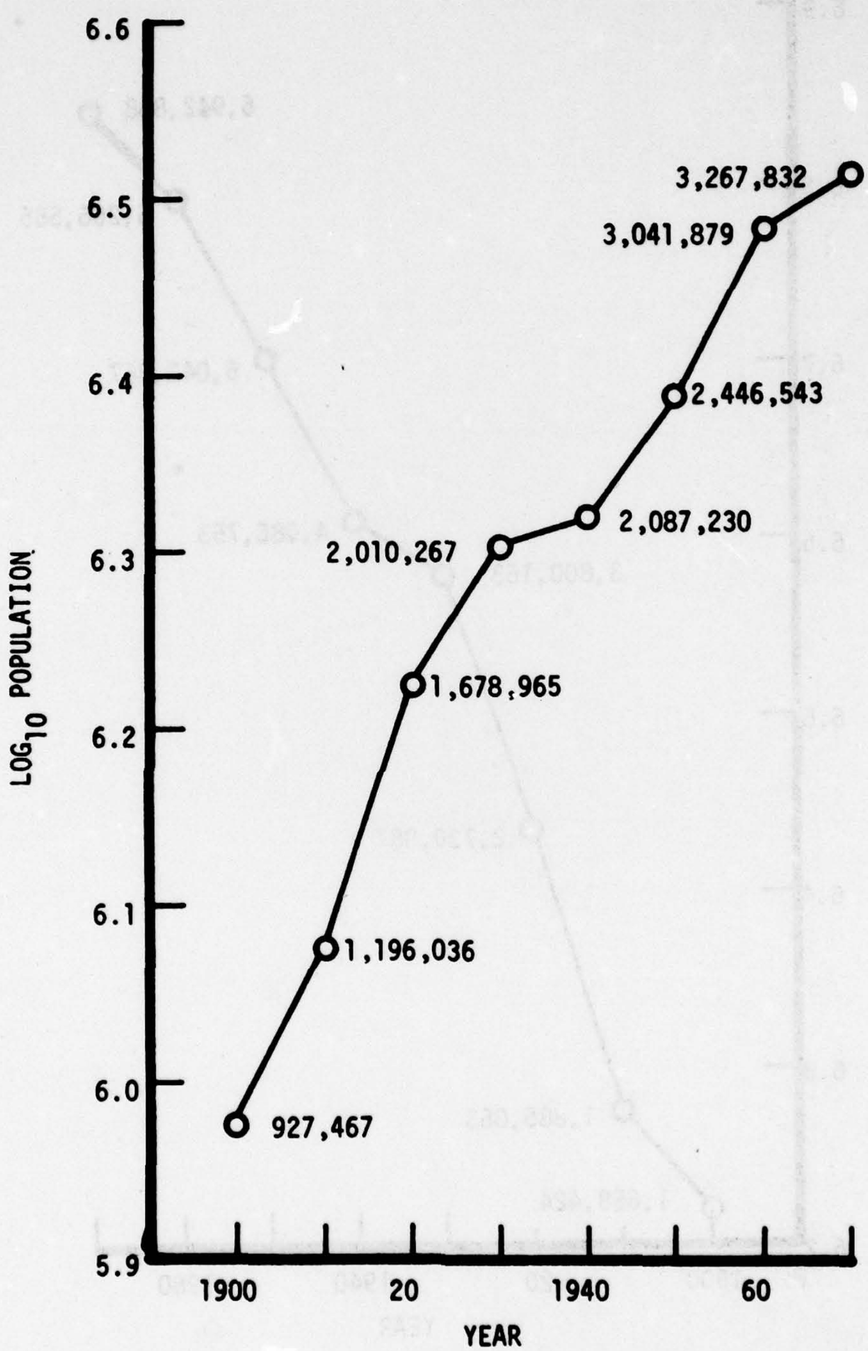

Fig. 2-3. POPULATION OF LAKE ERIE CENTRAL SUB-BASIN

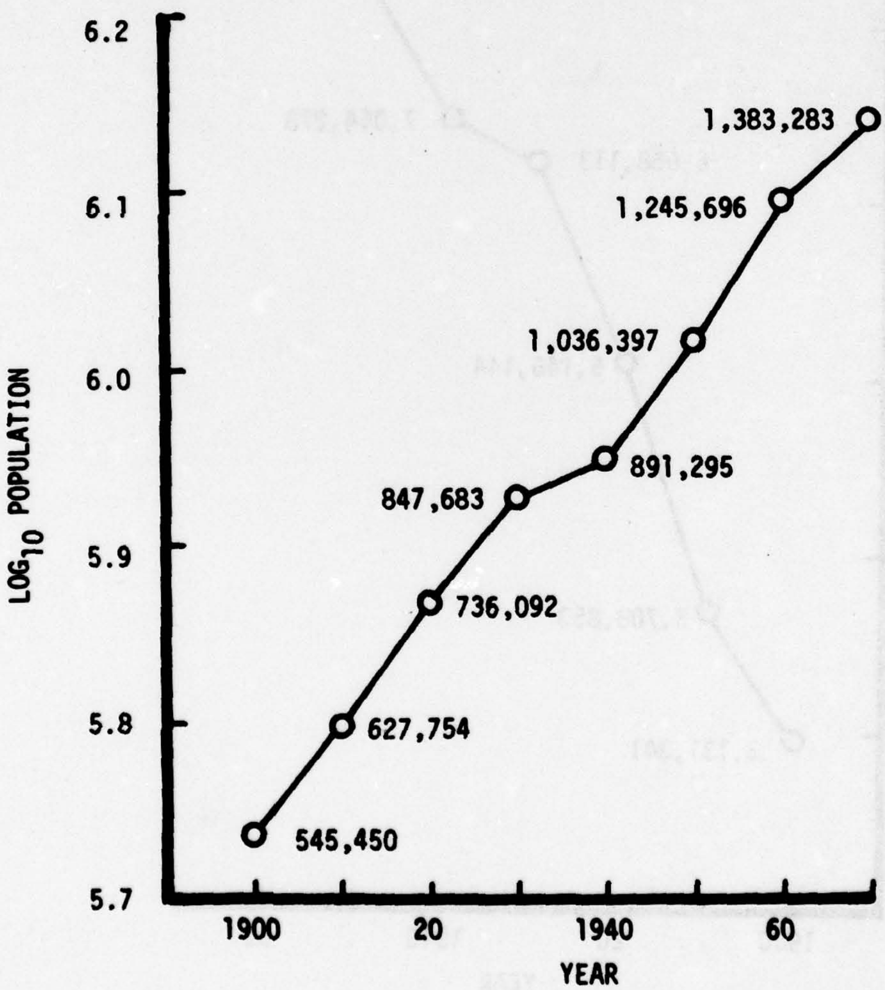

Fig. 2-4. POPULATION OF LAKE ERIE EASTERN SUB-BASIN

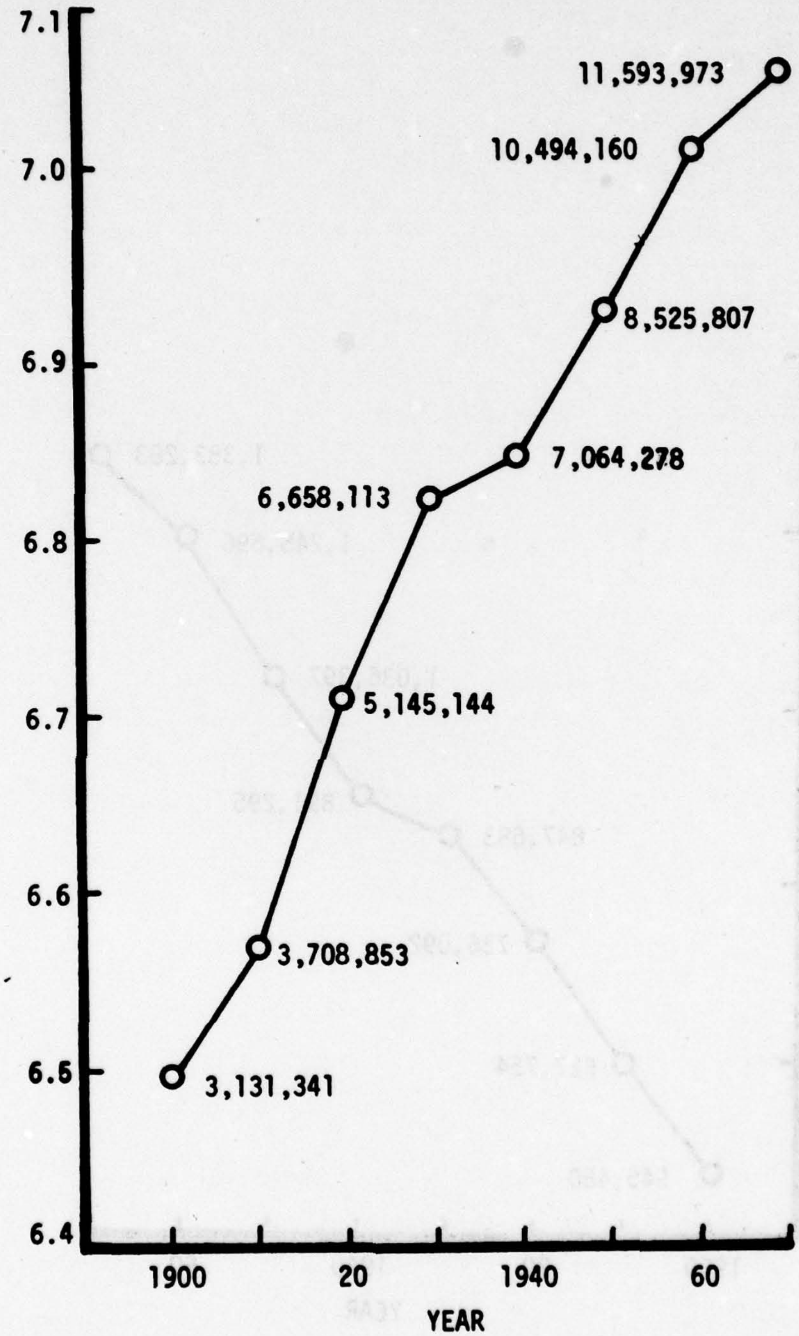

Fig. 2-5. POPULATION OF LAKE ERIE BASIN

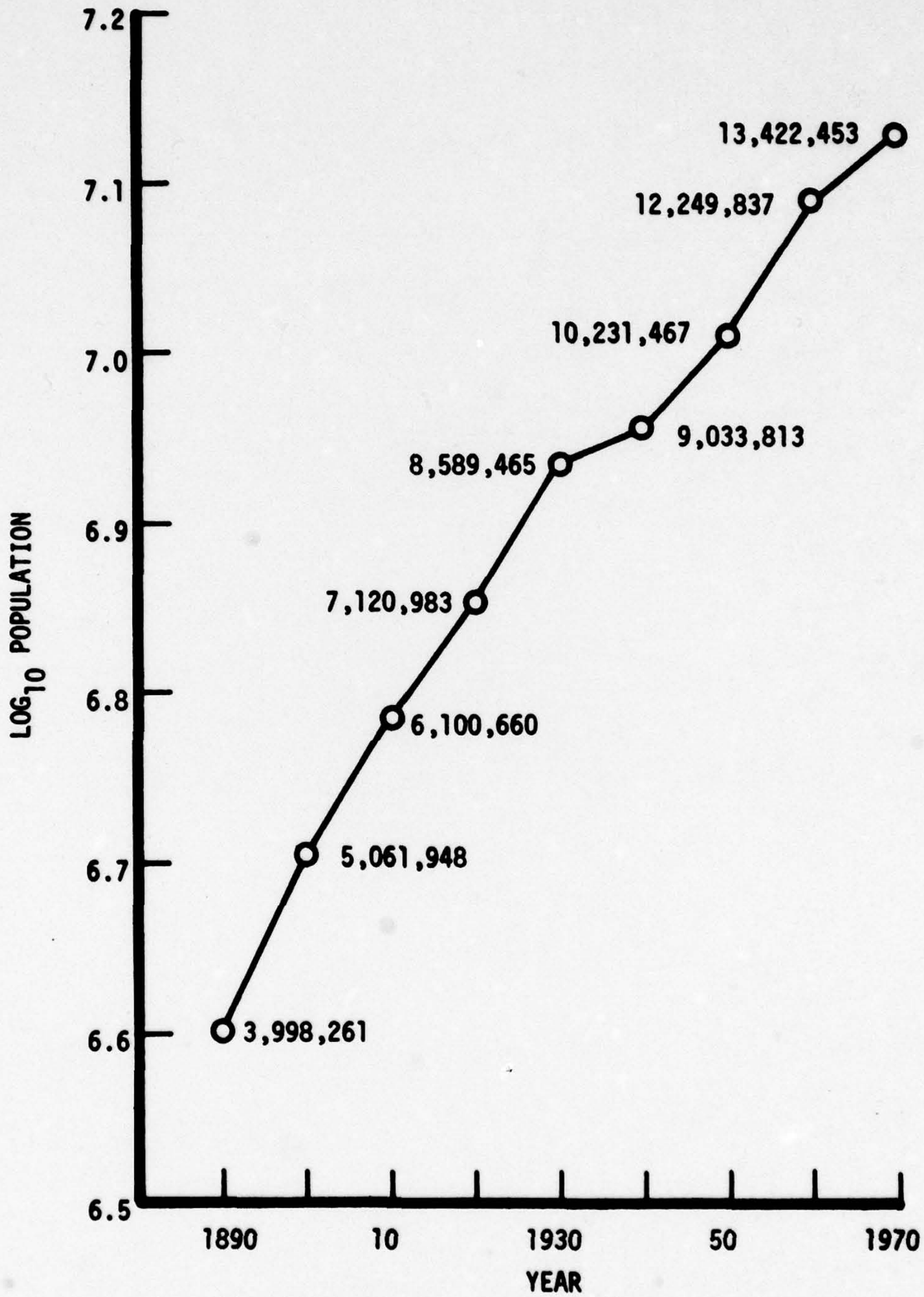

Fig. 2-6. POPULATION OF UPPER GREAT LAKES BASIN

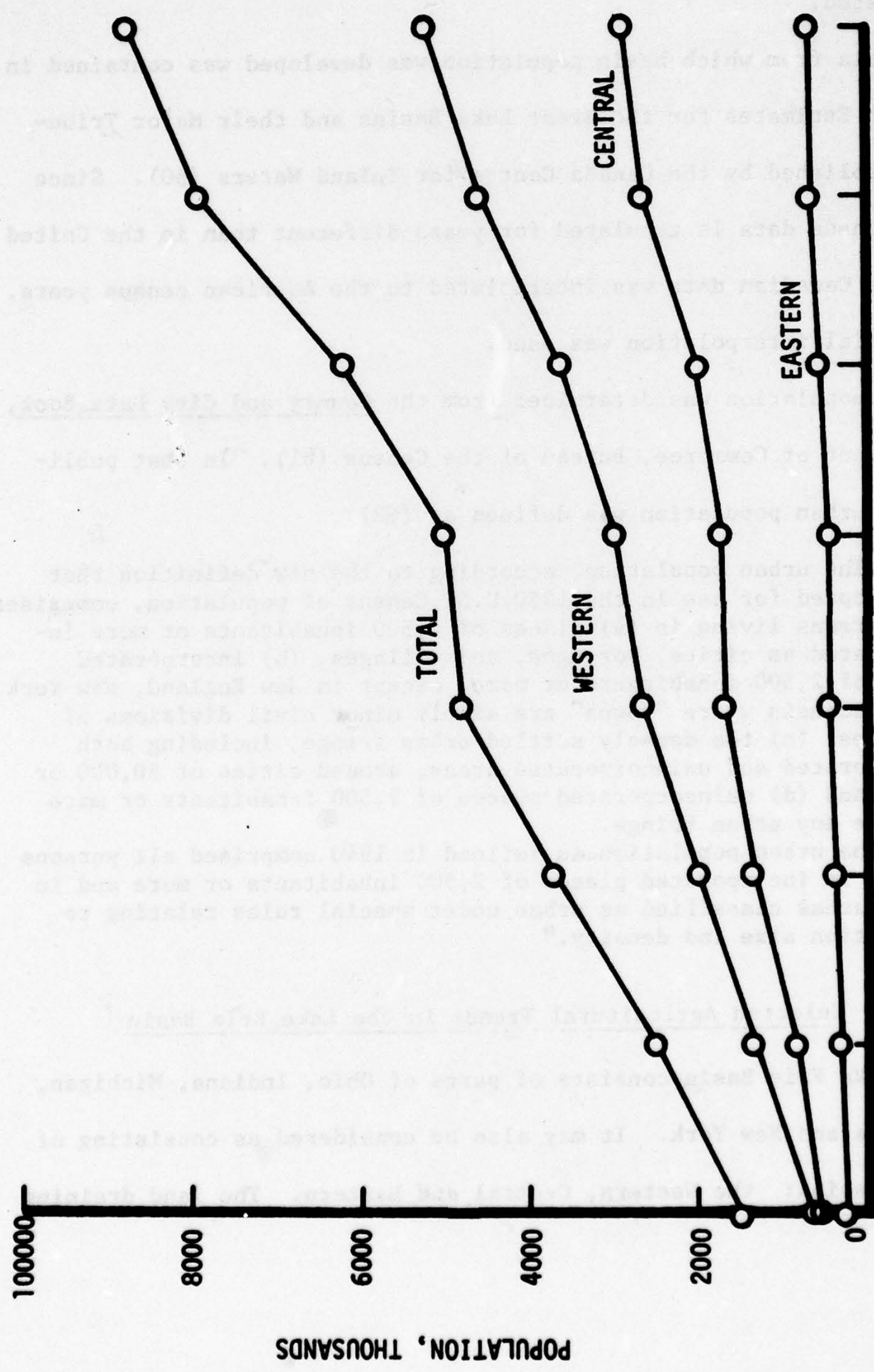

Fig. 2-7. U.S. URBAN POPULATION BY SUB-BASIN

down by county at the smallest level, sub-totals are derived for the Western, Central and Eastern Sub-Basins, as well as for the Basin as a whole. Furthermore, urban population in the United States only has been tabulated.

The data from which basin population was developed was contained in "Population Estimates for the Great Lake Basins and their Major Tributaries", published by the Canada Centre for Inland Waters (60). Since Canadian census data is tabulated for years different than in the United States, the Canadian data was interpolated to the American census years. An exponential interpolation was used.

Urban population was determined from the County and City Data Book, U.S. Department of Commerce, Bureau of the Census (61). In that publication the urban population was defined as (62):

> "The urban population, according to the new definition that was adopted for use in the 1950 U.S. Census of population, comprises all persons living in (a) places of 2,500 inhabitants or more incorporated as cities, boroughs, and villages; (b) incorporated towns of 2,500 inhabitants or more, except in New England, New York and Wisconsin where "towns" are simply minor civil divisions of counties; (c) the densely settled urban fringe, including both incorporated and unincorporated areas, around cities of 50,000 or more; and (d) unincorporated places of 2,500 inhabitants or more outside any urban fringe.
>
> The urban population as defined in 1940 comprised all persons living in incorporated places of 2,500 inhabitants or more and in other areas classified as urban under special rules relating to population size and density."

Selected Agricultural Trends in the Lake Erie Basin

The Lake Erie Basin consists of parts of Ohio, Indiana, Michigan, Pennsylvania and New York. It may also be considered as consisting of three sub-basins: the Western, Central and Eastern. The land draining

into the Detroit River and Lake St. Clair is not included in the basin in this report. Table 2.18 lists the states and counties that are at least partially contained within the three sub-basins along with the approximate fractions of county land areas lying within the Lake Erie Basin, the fractions of those areas within the relevent sub-basin, and the products of these two fractions. These final products were used as correction factors in order to modify raw data throughout this report, most of which was reported in terms of the whole county area. In this way agricultural trends were estimated in terms of the sub-basin areas.

Trends presented in this study are:

1.) Farm Animal Population from 1930 to 1969 including:
   a.) Cattle
   b.) Hogs and Pigs
   c.) Chickens

2.) Harvested Cropland from 1930 to 1969

3.) Fertilizer Use from 1950 to 1974 including:
   a.) Total fertilizers
   b.) Nitrogen put down
   c.) Phosphorus put down

4.) Selected Crops from 1935 to 1969 including:
   a.) Corn
   b.) Wheat
   c.) Soybeans

The presentation of these trends are followed by some conclusions and observations.

Table 2.18

CORRECTION FACTORS FOR COUNTY AREAS

	(1) Fraction in Lake Erie Basin	(2) Fraction in Western Basin	(1) x (2)
WESTERN BASIN			
Michigan			
Hillsdale	0.5	1.0	0.5
Lenawee	1.0	1.0	1.0
Monroe	1.0	1.0	1.0
Livingston	0.3	1.0	0.3
Oakland	0.2	1.0	0.2
Wayne	0.2	1.0	0.2
Washtenaw	0.9	1.0	0.9
Indiana			
Dekalb	1.0	1.0	1.0
Allen	0.7	1.0	0.7
Adams	0.8	1.0	0.8
Ohio			
Williams	1.0	1.0	1.0
Fulton	1.0	1.0	1.0
Lucas	1.0	1.0	1.0
Ottawa	1.0	1.0	1.0
Defiance	1.0	1.0	1.0
Henry	1.0	1.0	1.0
Wood	1.0	1.0	1.0
Sandusky	1.0	0.5	0.5
Hancock	1.0	1.0	1.0
Putnam	1.0	1.0	1.0
Paulding	1.0	1.0	1.0
Van Wert	1.0	1.0	1.0
Allen	1.0	1.0	1.0
Hardin	0.5	0.8	0.4
Auglaize	0.8	1.0	0.8
Mercer	0.6	1.0	0.6

Table 2.18 (continued)

	(1) Fraction in Lake Erie Basin	(2) Fraction in Central Basin	1 x 2
CENTRAL BASIN			
Ohio			
Sandusky	1.0	0.5	0.5
Erie	1.0	1.0	1.0
Lorain	1.0	1.0	1.0
Cuyahoga	1.0	1.0	1.0
Lake	1.0	1.0	1.0
Geauga	1.0	1.0	1.0
Ashtabula	0.8	1.0	0.8
Trumball	0.3	1.0	0.3
Portage	0.4	1.0	0.4
Summit	0.7	1.0	0.7
Medina	0.7	1.0	0.7
Ashland	0.2	1.0	0.2
Huron	1.0	1.0	1.0
Seneca	1.0	1.0	1.0
Wyandot	1.0	1.0	1.0
Crawford	0.8	1.0	0.8
Richland	0.1	1.0	0.1
Hardin	0.5	0.2	0.1
Marion	0.2	1.0	0.2
Pennsylvania			
Erie	0.6	0.5	0.3
Crawford	0.2	1.0	0.2
EASTERN BASIN			
Pennsylvania			
Erie	0.6	0.5	0.3
New York			
Chautauqua	0.3	1.0	0.3
Cattaraugus	0.3	1.0	0.3
Wyoming	0.3	1.0	0.3
Erie	1.0	1.0	1.0

Farm Animals Population (36)

Chickens

The chicken population has remained fairly constant for the Western Basin, but has dropped steadily for the Central and Eastern Basins since 1930 (Figure 2.8 and Table 2.19A). In general, the overall chicken population in Lake Erie started dropping in 1935 until 1960 but remained constant throughout the 60's due to a resurgence in the Western Basin.

Hogs and Pigs

The population of hogs and pigs in the Wastern Basin is negligible compared to the Central Basin, where it has remained constant for the past 40 years (Figure 2.9 and Table 2.20A). For the Western Basin, the population has fluctuated, reaching a low point in 1940. The highest population for the past 30 years was in 1959.

Cattle

The number of cattle in the Lake Erie Basin has been dropping for the past 25 years (Figure 2.10 and Table 2.21A). For the Eastern Basin the cattle population has remained fairly constant, but the Central Basin has shown a moderate, although steady increase. For the Western Basin, the dominant part of the whole Lake Erie watershed, the cattle population has dropped by about 20% since 1959. The cattle population has minimum numbers aroung 1940, possibly due to the restrictive conditions of the 2nd World War.

Harvested Cropland

Harvested cropland (Figure 2.11 and Table 2.22A) refers to all land from which crops were harvested, whether for home use or for sale. It includes land from which hay, including wild hay, was cut and land on which berries and other small fruits, orchards, vineyards, nurseries,

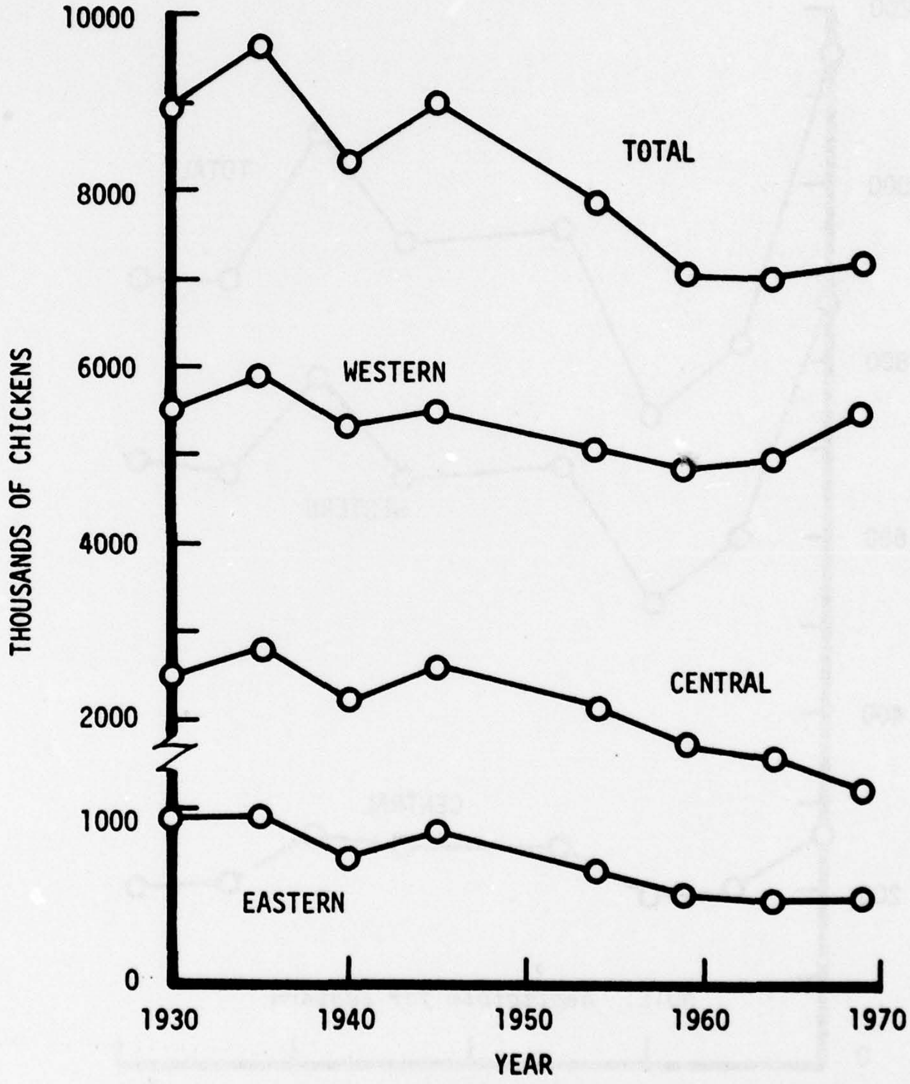

Fig. 2-8. CHICKENS BY BASIN

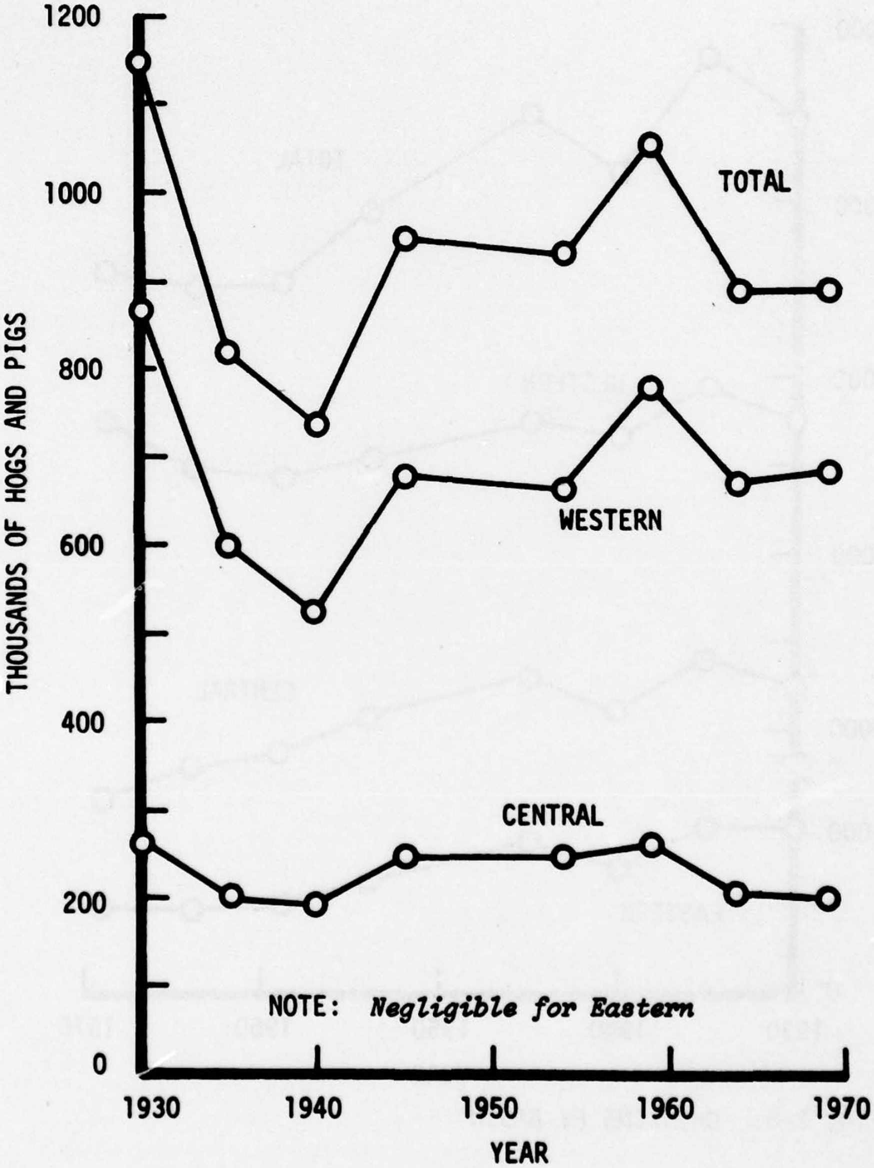

Fig. 2-9. HOGS AND PIGS BY BASIN

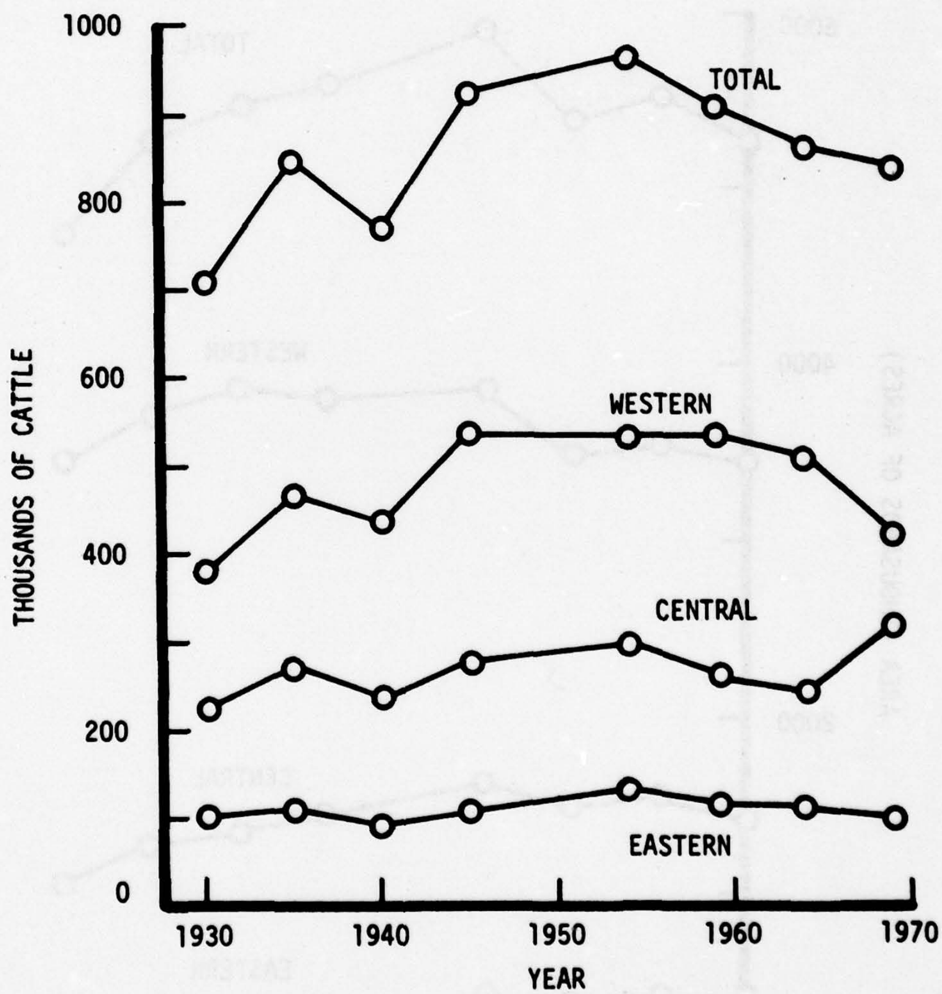

Fig. 2-10. CATTLE BY BASIN

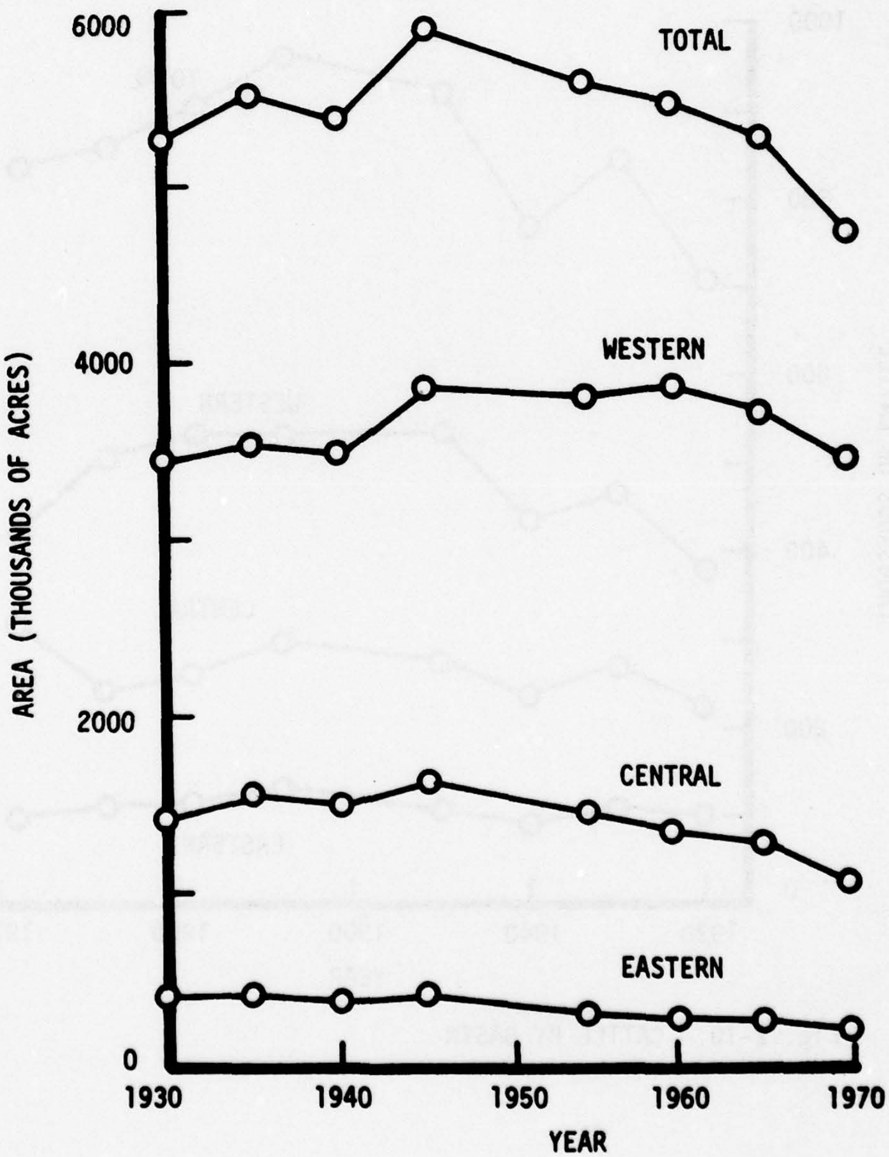

Fig. 2-11. HARVESTED CROPLAND BY BASIN

and green houses were grown. Matured crops which were hogged off or grazed were considered to have been "crops harvested" and were reported and counted in this category. Land from which two or more crops were harvested was counted only once.

The difference between cropland harvested and cropland planted is defined as crop failure. Crop failure usually amounts to less than 1% of the planted acreage.

Fertilizer Use

In analyzing fertilizer use the 25-year period from 1950 to 1974 has been considered. Three topics of interest are reported: 1) total fertilizer use; 2) total nitrogen applied; and 3) total phosphorus applied. Data came from state and federal sources (63, 64, 65).

Since much of the available fertilizer data was listed by state but not broken down by county, the amount of fertilizer corresponding to the area of each state draining into Lake Erie was determined by a straight percentage of each state's total fertilizer use. For the years that complete data for each county was available, the portion of fertilizer used in the Lake Erie Basin was calculated. Figures 2.12 and 2.13 show the plotted points. Complete data was available for all the states for 1954, 1959 and 1969 and Ohio for the years, 1966, 1968, 1970, 1971, 1972, 1973 and 1974. This Ohio data is listed in Table 2.23A. Linear graphical approximations were constructed for all the states, and percentage values for the other years in which only incomplete data was available were interpolated using this construction. These values are listed in Table 2.24A. In this way, statewide fertilizer data was adapted for use in the study. An interesting aspect which

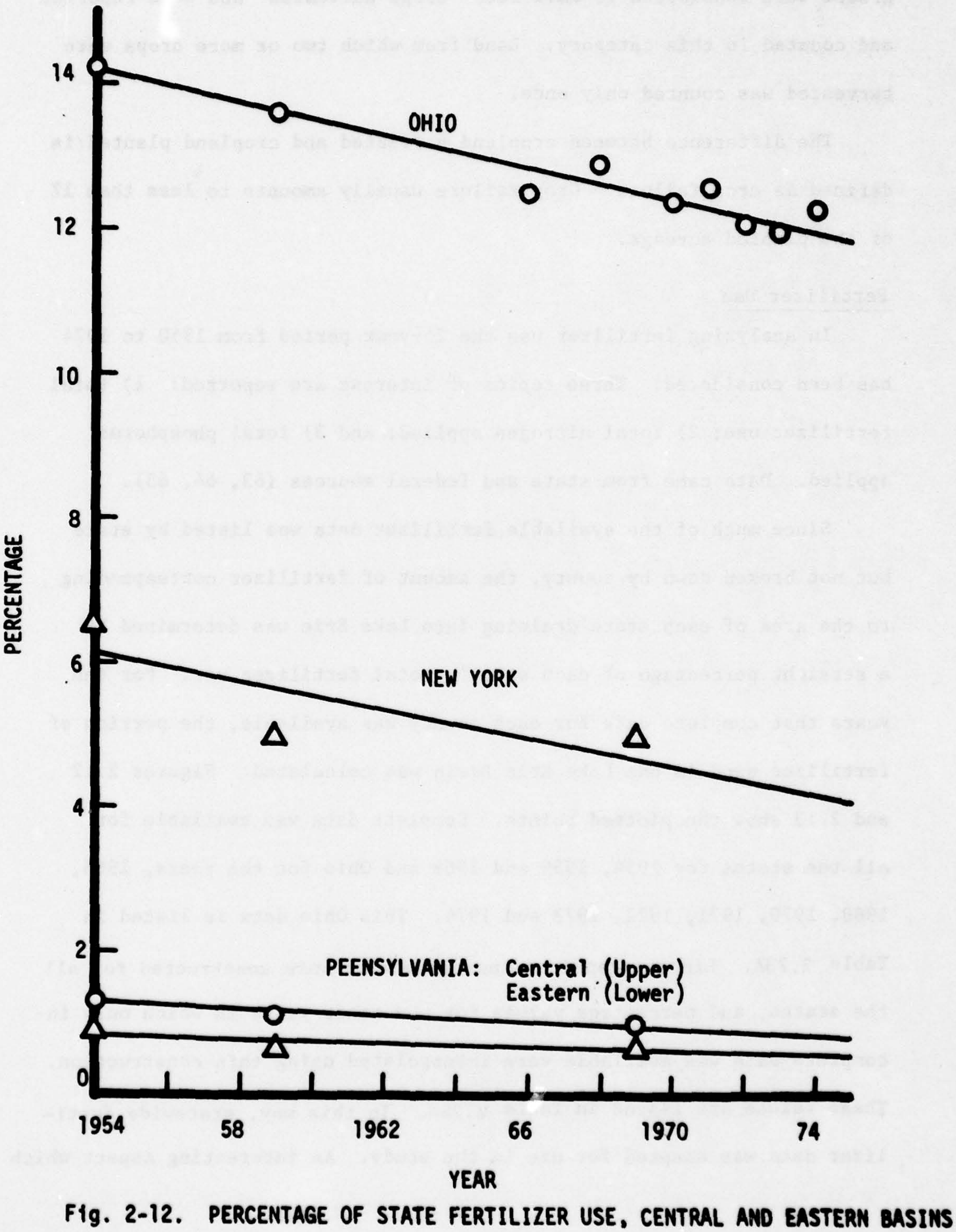

Fig. 2-12. PERCENTAGE OF STATE FERTILIZER USE, CENTRAL AND EASTERN BASINS

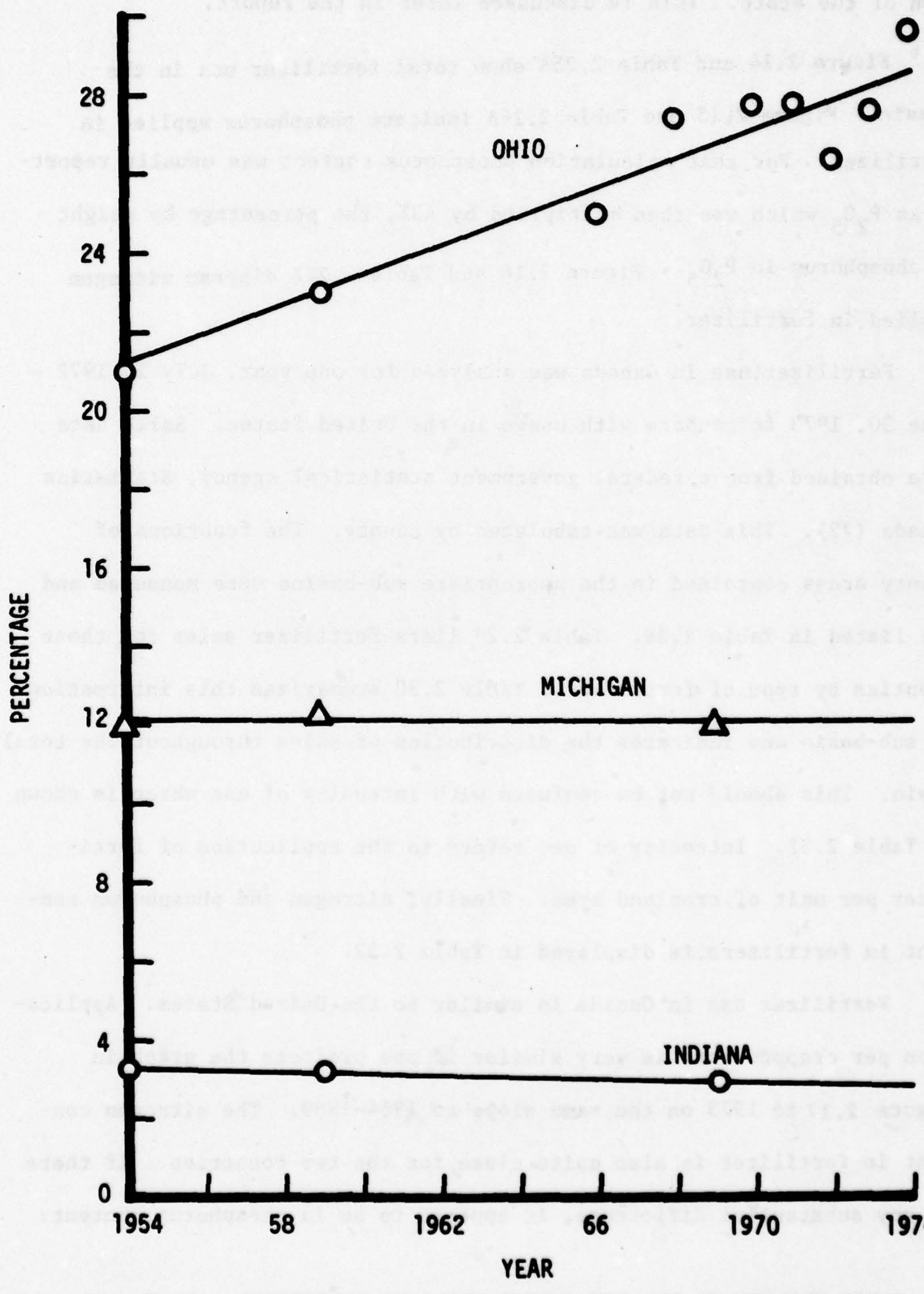

Fig. 2-13. PERCENTAGE OF STATE FERTILIZER USE IN WESTERN BASIN

was discovered was that a shift towards increased fertilizer use has occurred in Ohio from the east and south towards the north-western portion of the state. This is discussed later in the report.

Figure 2.14 and Table 2.25A show total fertilizer use in the Basin. Figure 2.15 and Table 2.26A indicate phosphorus applied in fertilizer. For that calculation phosphorus content was usually reported as P_2O_5 which was then multiplied by 43%, the percentage by weight of phosphorus in P_2O_5. Figure 2.16 and Table 2.27A diagram nitrogen applied in fertilizer.

Fertilizer use in Canada was analyzed for one year, July 1, 1972 - June 30, 1973 to compare with usage in the United States. Sales data were obtained from a federal government statistical agency, Statistics Canada (72). This data was tabulated by county. The fractions of county areas contained in the appropriate sub-basins were measured and are listed in Table 2.28. Table 2.29 lists fertilizer sales for those counties by type of fertilizer. Table 2.30 summarizes this information by sub-basin and indicates the distribution of sales throughout the total basin. This should not be confused with intensity of use which is shown in Table 2.31. Intensity of use refers to the application of fertilizer per unit of cropland area. Finally, nitrogen and phosphorus content in fertilizers is displayed in Table 2.32.

Fertilizer use in Canada is similar to the United States. Application per cropped acre is very similar if one projects the graph in Figure 2.17 to 1973 on the same slope as 1964-1969. The nitrogen content in fertilizer is also quite close for the two countries. If there is any substantial difference, it appears to be in phosphorus content:

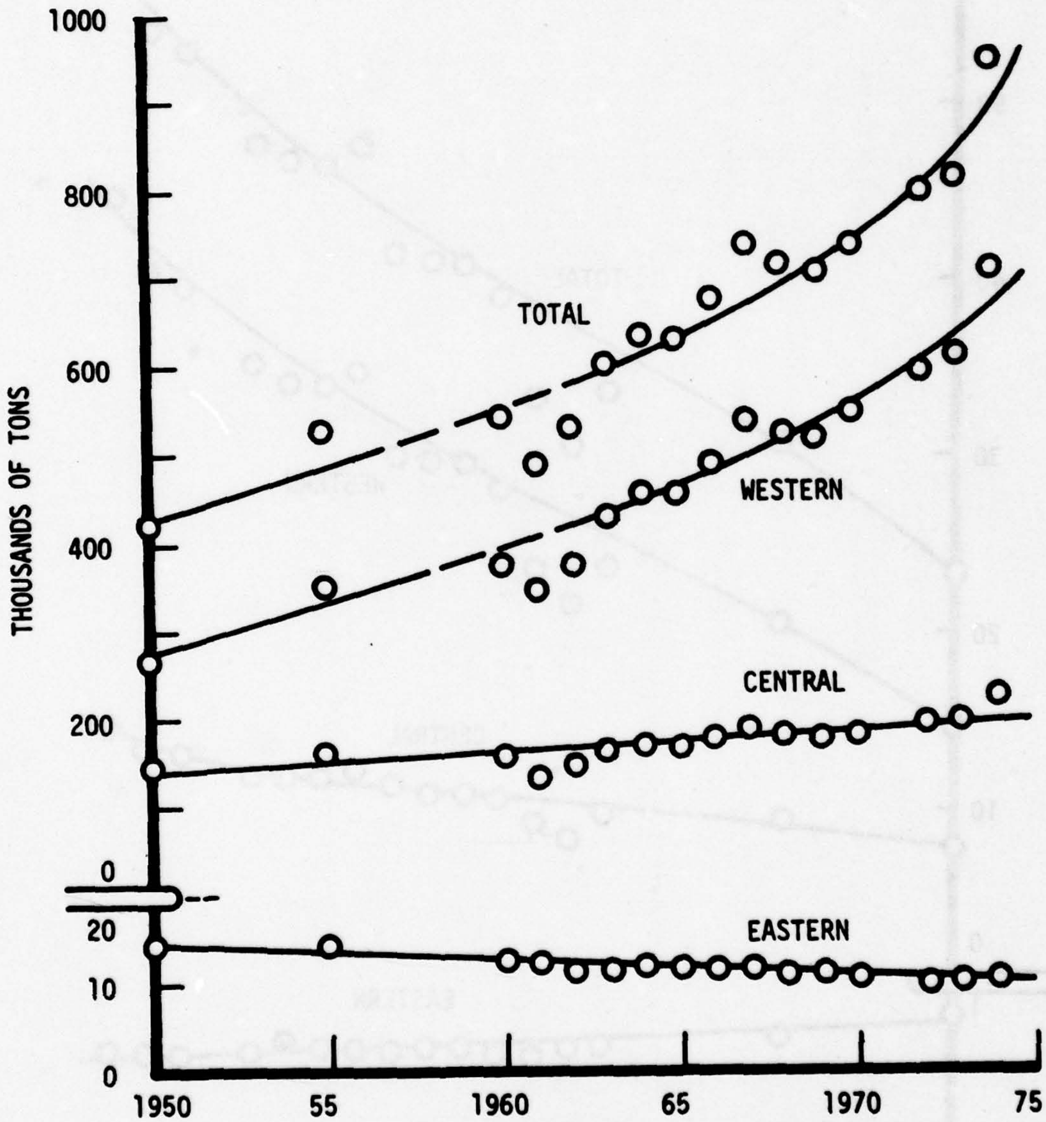

Fig. 2-14. TOTAL FERTILIZER USE IN U.S. BY SUB-BASIN

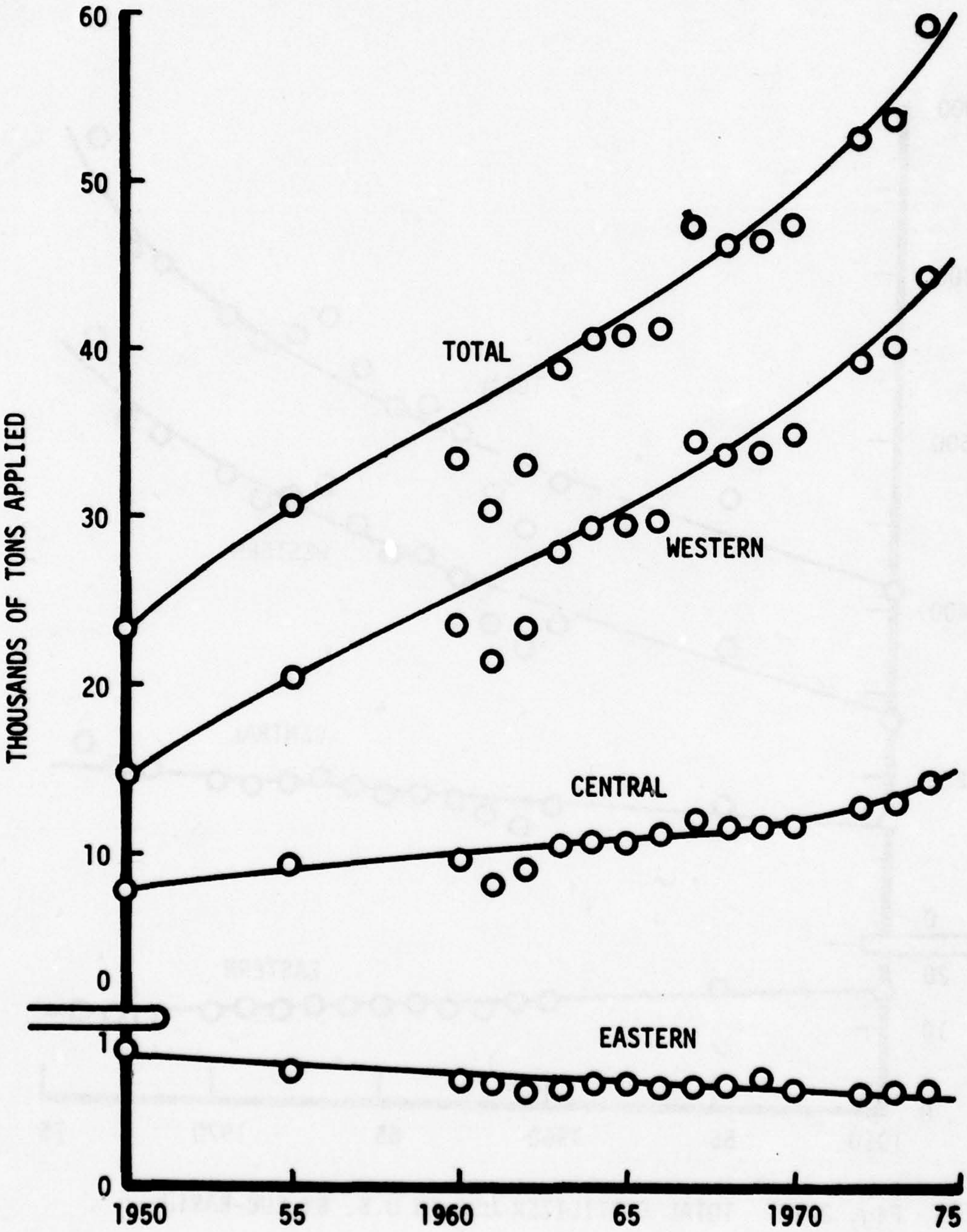

Fig. 2-15. PHOSPHOROUS IN FERTILIZERS APPLIED IN U.S. BY BASIN

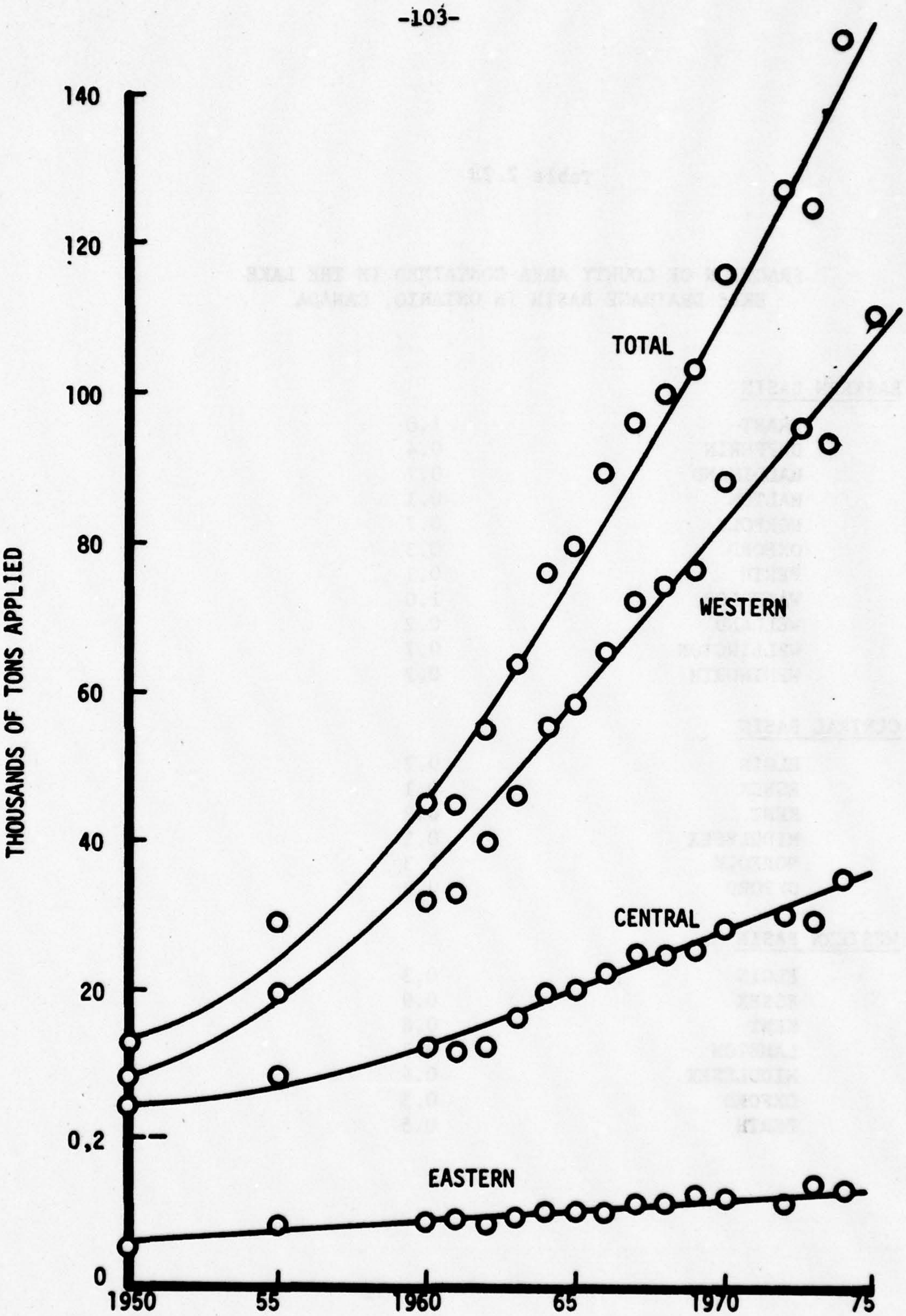

Fig. 2-16. NITROGEN IN FERTILIZERS APPLIED IN U.S. BY BASIN

Table 2.28

FRACTION OF COUNTY AREA CONTAINED IN THE LAKE ERIE DRAINAGE BASIN IN ONTARIO, CANADA

EASTERN BASIN	
BRANT	1.0
DUFFERIN	0.4
HALDIMAND	0.7
HALTON	0.1
NORFOLK	0.7
OXFORD	0.3
PERTH	0.1
WATERLOO	1.0
WELLAND	0.2
WELLINGTON	0.7
WENTWORTH	0.2
CENTRAL BASIN	
ELGIN	0.7
ESSEX	0.1
KENT	0.2
MIDDLESEX	0.1
NORFOLK	0.3
OXFORD	0.2
WESTERN BASIN	
ELGIN	0.3
ESSEX	0.9
KENT	0.8
LAMBTON	0.7
MIDDLESEX	0.6
OXFORD	0.5
PERTH	0.5

Table 2.29

COUNTY DISTRIBUTION OF FERTILIZERS SOLD IN THE LAKE ERIE DRAINAGE BASIN IN ONTARIO DURING THE YEAR ENDED JUNE 30, 1973

	MATERIALS (Tons)	MIXED FERTILIZERS (Tons)	TOTAL (Tons)
EASTERN BASIN			
BRANT	6,754	14,141	20,895
DUFFERIN	958	3,833	4,791
HALDIMAND	3,582	3,065	6,647
HALTON	180	503	683
NORFOLK	9,577	30,789	40,366
OXFORD	7,215	7,700	14,915
PERTH	1,441	2,106	3,547
WATERLOO	14,372	12,396	26,768
WELLAND	365	741	1,106
WELLINGTON	6,648	11,518	18,166
WENTWORTH	849	1,561	2,410
SUBTOTAL	51,941	88,353	140,294
CENTRAL BASIN			
ELGIN	14,335	25,241	39,576
ESSEX	2,246	3,087	5,333
KENT	10,816	12,761	23,577
MIDDLESEX	2,906	4,138	7,044
NORFOLK	4,105	13,195	17,300
OXFORD	4,810	5,133	9,943
SUBTOTAL	39,218	63,555	102,773
WESTERN BASIN			
ELGIN	6,143	10,818	16,961
ESSEX	20,218	27,787	48,005
KENT	43,262	51,046	94,308
LAMBTON	17,310	19,038	36,348
MIDDLESEX	17,435	24,826	42,261
OXFORD	12,026	12,832	24,858
PERTH	7,205	10,529	17,734
SUBTOTAL	123,599	156,876	280,475
TOTAL	214,758	308,784	523,542

Table 2.30

SUMMARY OF FERTILIZER SALES DATA FOR THE LAKE ERIE BASIN IN CANADA 7/1/72-6/30/73

	MATERIALS[9]		MIXED FERTILIZERS		TOTAL	
	Sales[12] (tons)	% of Total[16] L.E. Basin	Sales (tons)	% of Total L.E. Basin	Sales (tons)	% of Total L.E. Basin
EASTERN BASIN[13]	51,941	24.2	88,353	28.6	140,294	26.8
CENTRAL BASIN	39,218	18.3	63,555	20.6	102,773	19.6
WESTERN BASIN	123,599	57.5	156,876	50.8	280,475	53.6
TOTAL LAKE ERIE BASIN[16]	214,758	100.0	308,784	100.0	523,542	100.0

Table 2.31

FERTILIZER PER ACRE DEVOTED TO CROPS
IN THE LAKE ERIE BASIN IN CANADA
YEAR ENDING JUNE 30, 1973

	Cropland (Acres)	Total Fertilizer Per Cropland Acre (Tons/Acre)
EASTERN BASIN	1,012,046	0.139
CENTRAL BASIN	452,844	0.227
WESTERN BASIN	1,499,728	0.187
TOTAL LAKE ERIE BASIN	2,964,618	0.177

Table 2.32

NITROGEN (N) AND PHOSPHORUS (P) IN FERTILIZERS SOLD
IN LAKE ERIE DRAINAGE BASIN IN CANADA
YEAR ENDED 7/30/73

	N (Tons)	P (Tons)	% N in Total Fertilizers	% P in Total Fertilizers
EASTERN BASIN	21,121	9,135		
CENTRAL BASIN	15,446	6,680		
WESTERN BASIN	42,241	18,269		
TOTAL LAKE ERIE BASIN	78,808	34,084	15.1	3.5

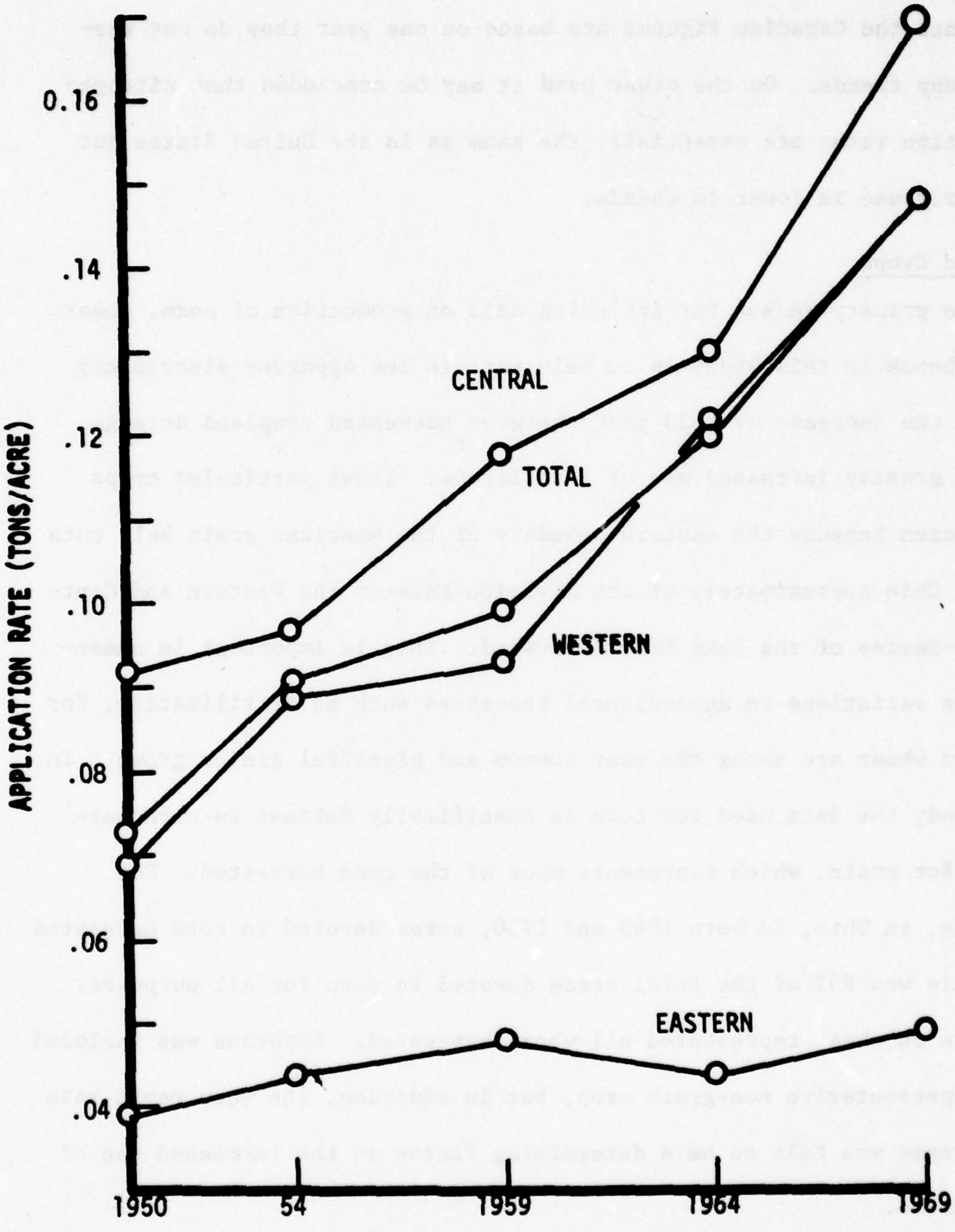

Fig. 2-17. FERTILIZER APPLICATION RATE IN U.S. BY SUB-BASIN

in 1973 it was calculated to be 6.7% in the U.S. and 3.5% in Canada (Table 2.32).

Since the Canadian figures are based on one year they do not represent any trends. On the other hand it may be concluded that nitrogen application rates are essentially the same as in the United States but phosphorus use is lower in Canada.

Selected Crops

The primary reason for including data on production of corn, wheat and soybeans in this study is to help explain the apparent discrepancy between the decrease over 20 years between harvested cropland acreage and the greatly increased use of fertilizers. These particular crops were chosen because the eastern boundary of the American grain belt cuts through Ohio approximately at the division between the Western and Central Sub-Basins of the Lake Erie watershed. This is important in understanding variations in agricultural practices such as fertilization, for corn and wheat are among the most common and plentiful grains grown. In this study the data used for corn is specifically defined as corn harvested for grain, which represents most of the corn harvested. For instance, in Ohio, in both 1945 and 1950, acres devoted to corn harvested for grain was 95% of the total acres devoted to corn for all purposes. The data on wheat represented all wheat harvested. Soybeans was included as a representative non-grain crop, but in addition, its very rapid rate of increase was felt to be a determining factor in the increased use of fertilizers.

Figure 2.18 and Table 2.33A show trends in wheat harvested since 1935 (63). In the Central and Eastern Basins the harvest generally

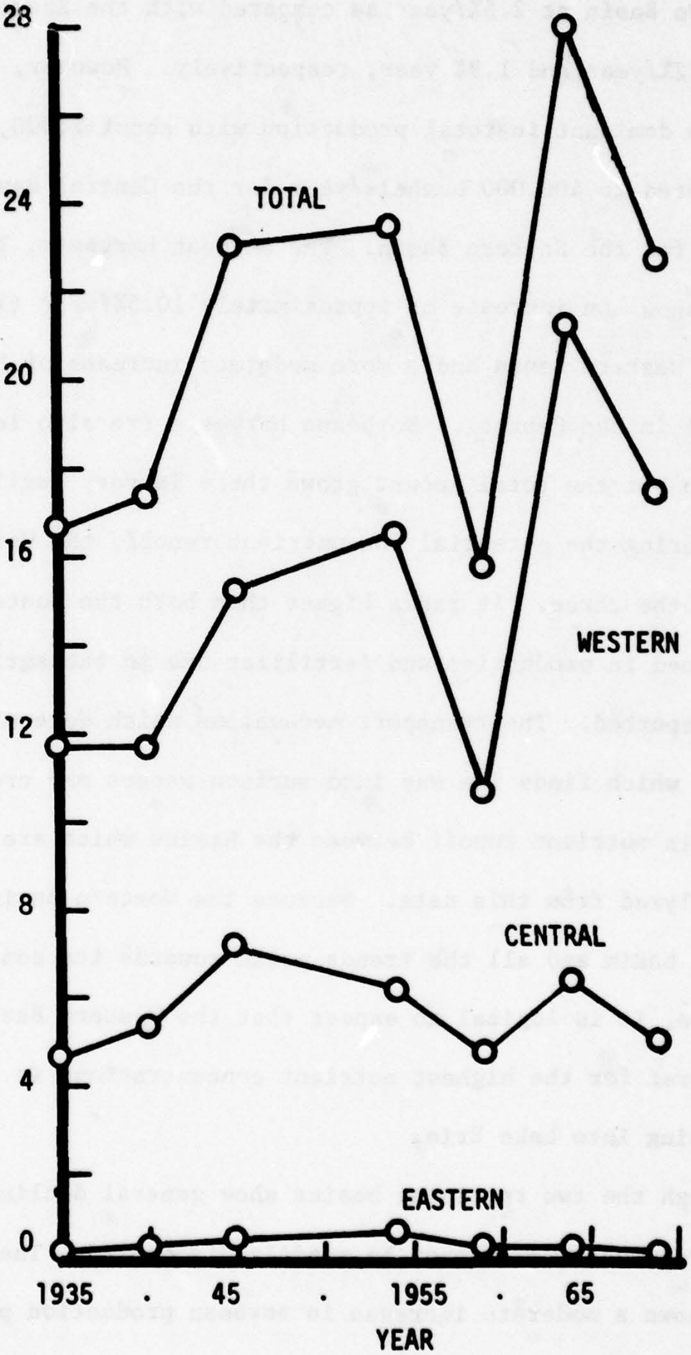

Fig. 2-18 WHEAT HARVESTED IN U.S. BY SUB-BASIN

increased at about 1.3%/year or 300,000 bushels/year. Figure 2.19 and Table 2.34A show trends for corn. Corn has shown the greatest increase in the Western Basin at 2.5%/year as compared with the Eastern and Central at 2.2%/year and 1.9% year, respectively. However, the Western Basin is also dominant in total production with about 2,000,000 bushels/year as compared to 400,000 bushels/year for the Central Basin and 15,000 bushels/year for the Eastern Basin. The soybean harvests, Figure 2.20 and Table 2.35A show an increase of approximately 10.5%/year (1,000,000 bushel/year) in the Western Basin and a more moderate increase of 6.3% (about 500,000 bushels/year) in the Central. Soybeans harvests are also increasing in the Eastern Basin but the total amount grown there is very small.

Considering the potential for nutrient runoff, the Western Basin is the worst of the three. It ranks higher than both the Eastern and Central Basins combined in production and fertilizer use in the agricultural categories reported. The transport mechanisms which determine the quantity of nutrients which finds its way into surface waters may create actual differences in nutrient runoff between the basins which are not capable of being analyzed from this data. Because the Western Basin is the dominant agricultural basin and all the trends point towards its continuing to be so in the future, it is logical to expect that the Western Basin is the area to be monitored for the highest nutrient concentrations in the surface waters draining into Lake Erie.

Although the two remaining basins show general declines in importance as growing regions, they cannot be readily discounted. The Central Basin has shown a moderate increase in soybean production plus a steady

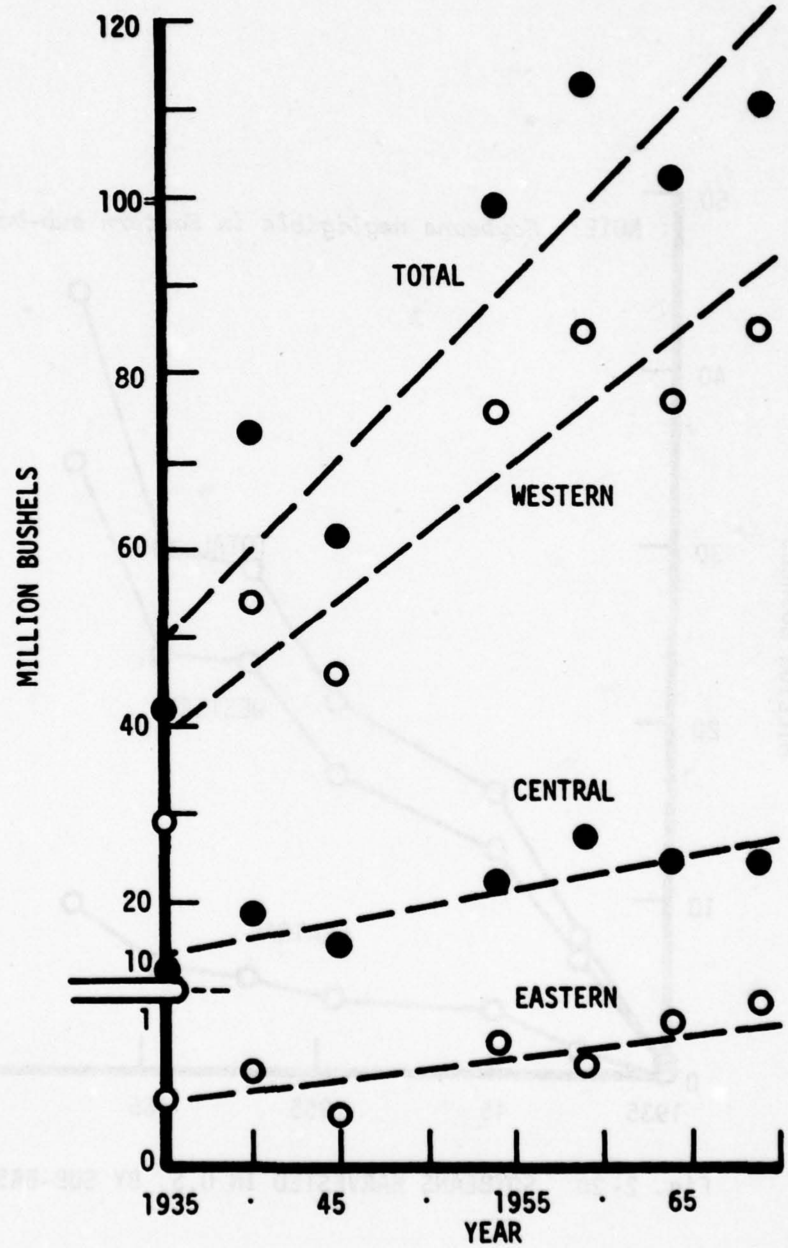

Fig. 2-14. CORN HARVESTED IN U.S. BY SUB-BASIN

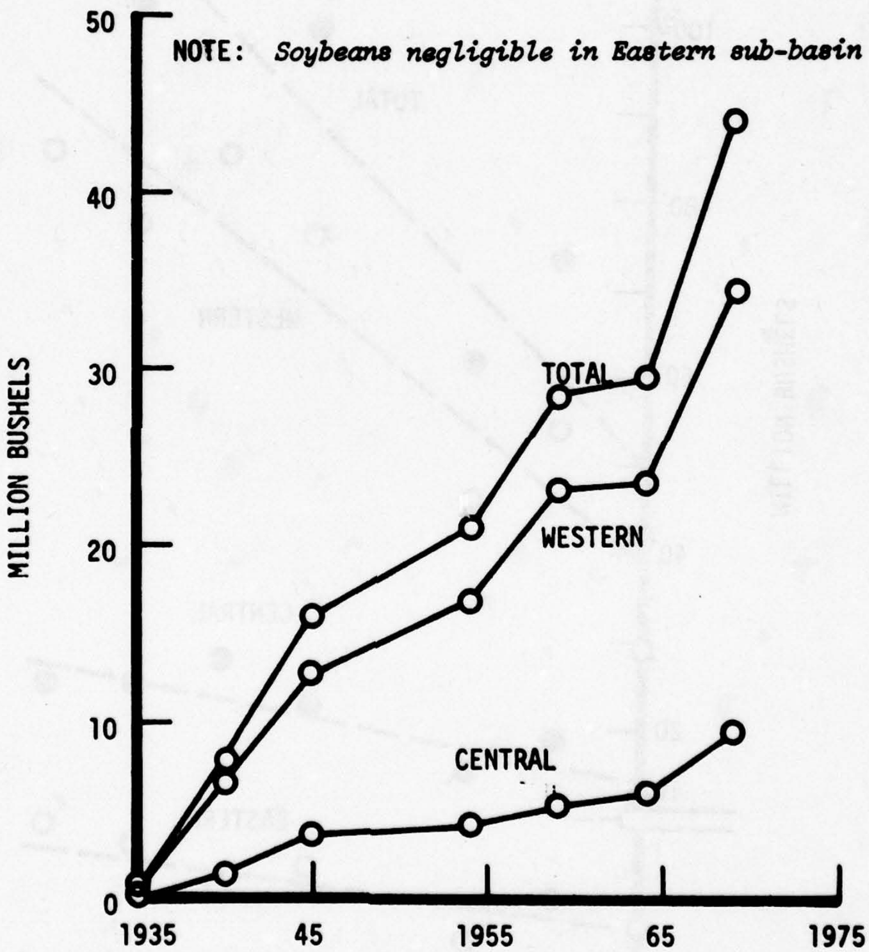

Fig. 2-20 SOYBEANS HARVESTED IN U.S. BY SUB-BASIN

increase in cattle population. Associated with the latter will be fertilized pastureland and acres of planted feed grain.

It is apparent from Figure 2.7 that the Western Basin possesses not only the largest total and urban populations but the largest rate of increase in urban population among the three sub-basins. The Western Basin is consequently the leader in virtually all categories of contaminant production which have been considered here, followed by the Central and then the Eastern.

In summary, the use of nitrogen in fertilizers has been increasing at an astonishing rate. The average nitrogen content in fertilizers has multiplied by a factor of 5 in the past twenty-five years and in addition, the general use of fertilizers has been steadily increasing.

The assembled data show the Western Basin to be the most substantial source of nutrients.

Simultaneous Trends

Undoubtedly the single most significant trend uncovered in this report is the increase in the amount and concentration of nitrogen applied to the soil in fertilizers. It is the result of three simultaneous trends: (1) a general increase in the use of fertilizers, (2) a substantial increase in the nitrogen content of fertilizers, and (3) a slow but constant decrease in the area of land devoted to crops.

In 1950, the average content of nitrogen in fertilizers was approximately 3%, less than the content in manure, which ranges from 10 to 20%. In the past twenty-five years that content has increased by a factor of 5. Figure 2.21 and Table 2.36A demonstrate that the average annual rate of increase between 1950 and 1970 was at 9%/year in the Central and

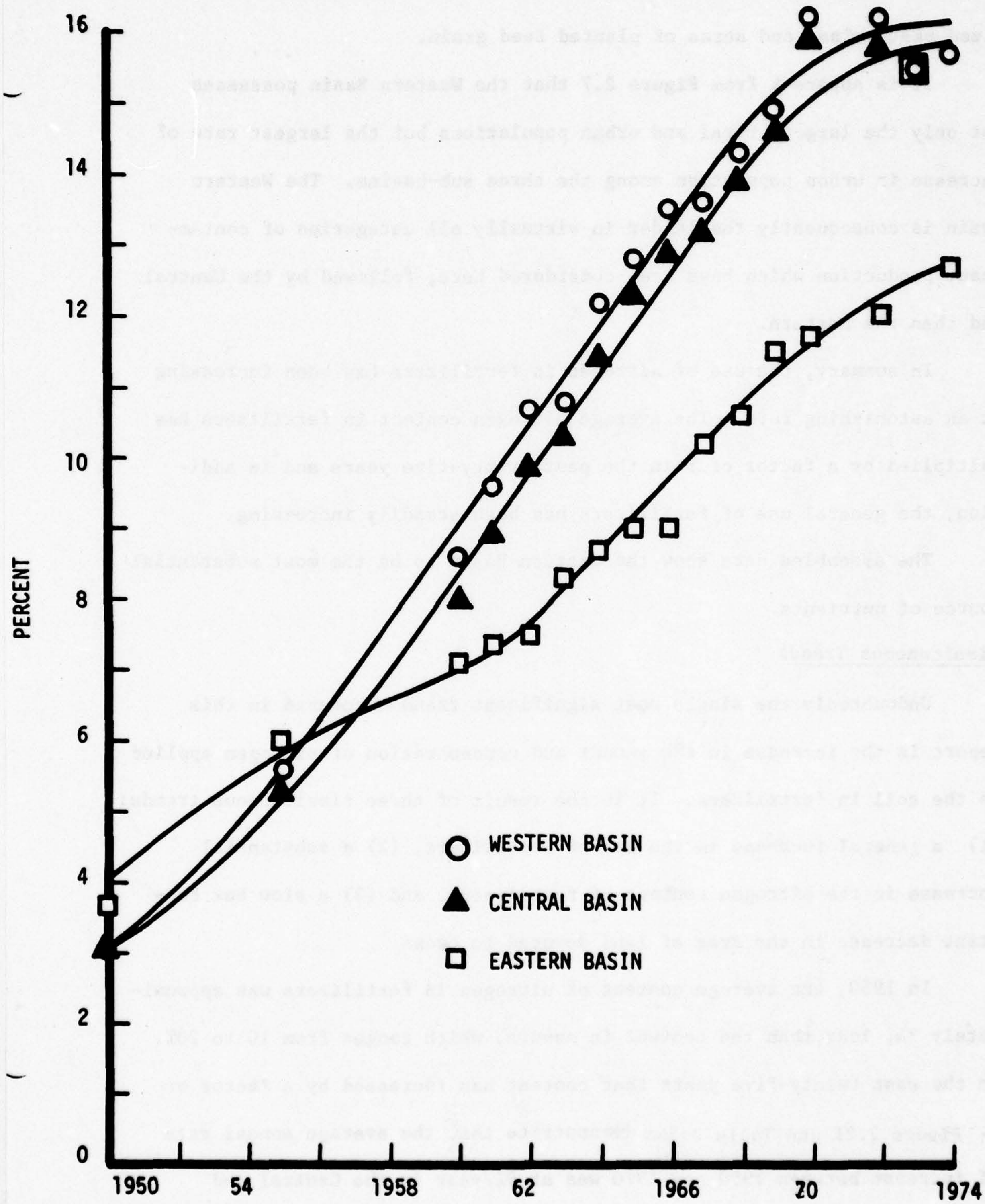

Fig. 2-23. PERCENTAGE OF NITROGEN IN FERTILIZERS

Western Basins and approximately 5%/year in the Eastern. There is no reason to believe that this trend will not continue. In Figure 2.22 is plotted the recent historical use of various nitrogen-bearing fertilizers. These compounds applied directly to the soil are becoming increasingly popular in contrast to the traditional mixed fertilizers. This substitution is demonstrated in Figure 2.23 Considering that these compounds all contain more nitrogen than the present average of 16% and considering the steady increase of nitrogen application it must be concluded that nitrogen use will continue to rise dramatically in the future. It may be questioned whether the strong increase in soybean production as seen in Figure 2.20 is at least partially responsible for the increased nitrogen use. However, the 1974-75 Agronomy Guide of Ohio State University states that "The soybean is a legume and can fix adequate atmospheric nitrogen to produce a yield of at least 60 to 70 bushels per acre. Research has shown that added nitrogen in fertilizer has produced no significant yield increase" (66). Therefore, the two trends do not seem to be connected.

The primary contributing factor in the intensified use of fertilizers is the desire for larger crop yields due to the decrease in acreage devoted to crops. Figure 2.11 displays the generally downward trend in acreage. In Figure 2.17 and Table 2.37A are displayed the fertilizer application per acre and the two-fold increase in the 20 years from 1950-1970 in the Western and Central Basins.

Phosphorus is another plant nutrient whose use in agriculture has increased. Although the percentage in fertilizer has only changed

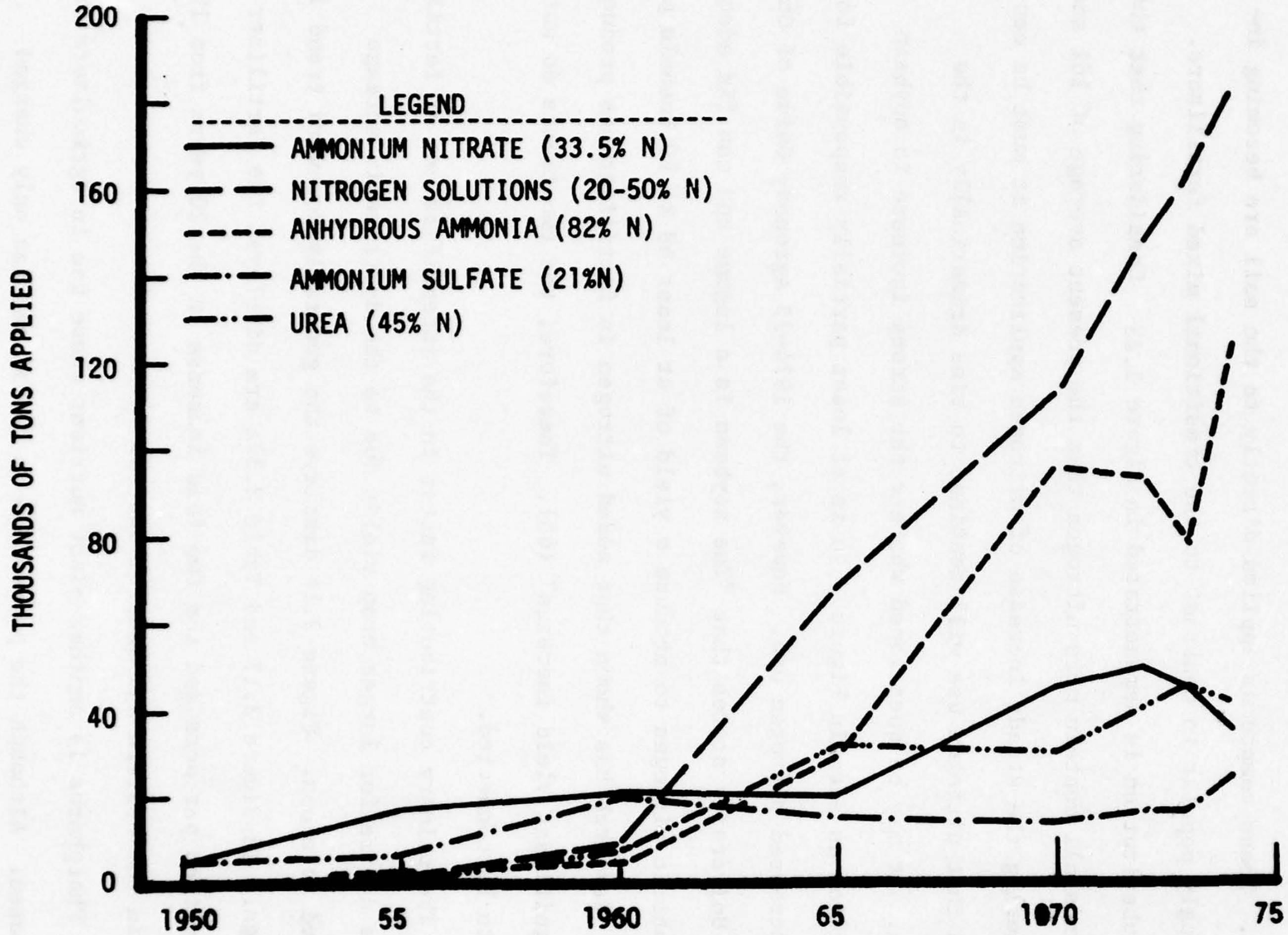

Fig. 2-22. NITROGEN CONTENT AND APPLICATION OF SELECTED FERTILIZERS IN OHIO

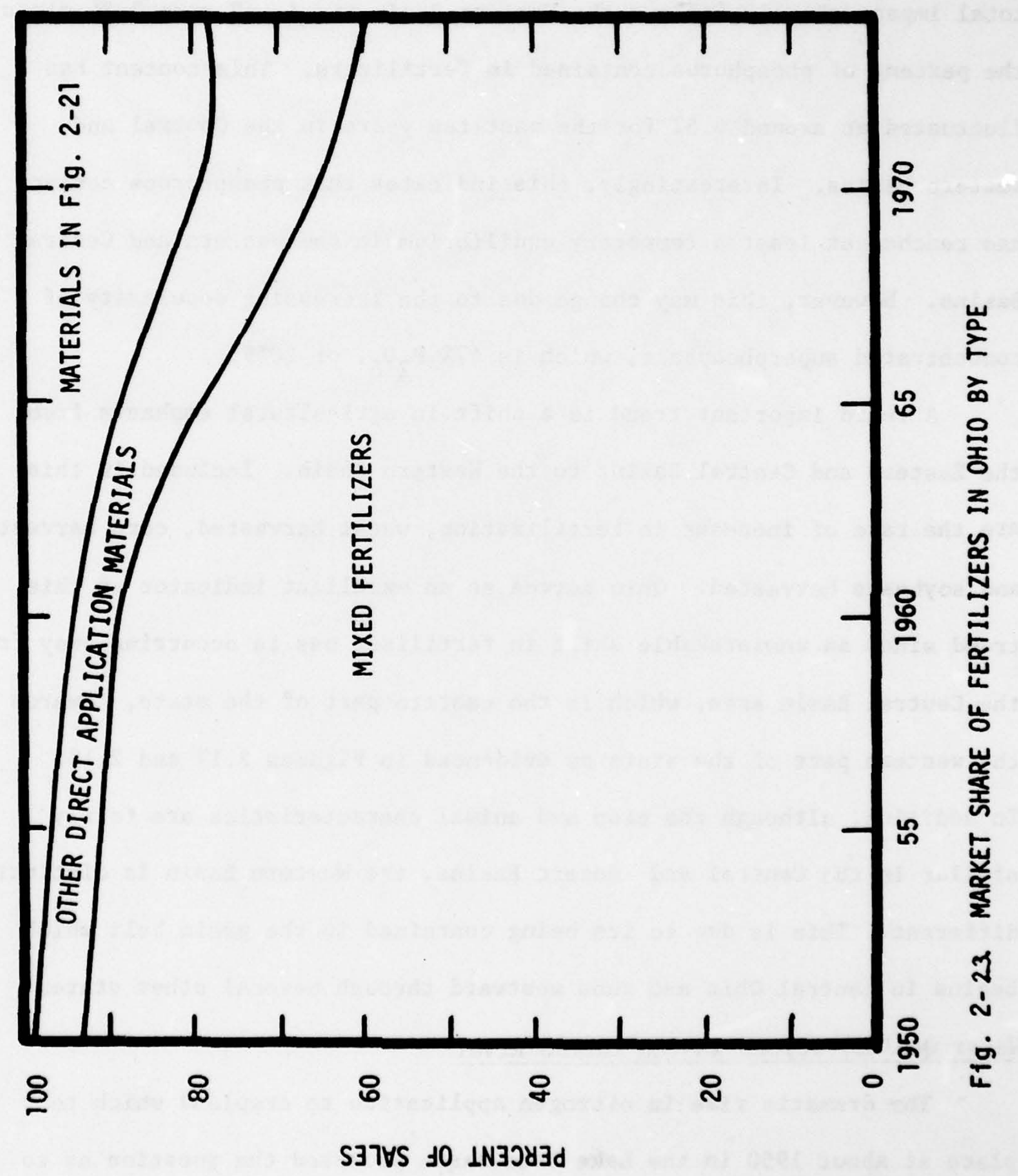

Fig. 2-23 MARKET SHARE OF FERTILIZERS IN OHIO BY TYPE

about 1% in the past 25 years as indicated in Figure 2.24 and Table 2.38A Figure 2.15 points out that the amount applied has tripled in the Western Basin, doubled in the Central and decreased slightly in the Eastern. The total impact closely follows the Western Basin trend. Figure 2.24 plots the percent of phosphorus contained in fertilizers. This content has fluctuated at around 6.5% for the past ten years in the Central and Western basins. Interestingly, this indicates that phosphorous content has reached at least a temporary equilibrium in the Western and Central Basins. However, this may change due to the increasing popularity of concentrated superphosphate, which is 47% P_2O_5, or 20%P.

A third important trend is a shift in agricultural emphasis from the Eastern and Central Basins to the Western Basin. Included in this are the rate of increase in fertilization, wheat harvested, corn harvested and soybeans harvested. Ohio serves as an excellent indicator of this trend since an unmistakable shift in fertilizer use is occurring away from the Central Basin area, which is the eastern part of the state, towards the western part of the state as evidenced in Figures 2.12 and 2.13. In addition, although the crop and animal characteristics are fairly similar in the Central and Eastern Basins, the Western Basin is distinctly different. This is due to its being contained in the grain belt which begins in central Ohio and runs westward through several other states.

Water Quality Trends in the Maumee River

The dramatic rise in nitrogen application to cropland which took place at about 1950 in the Lake Erie Basin prompted the question as to what might have been the impact, if any, of these agricultural practices

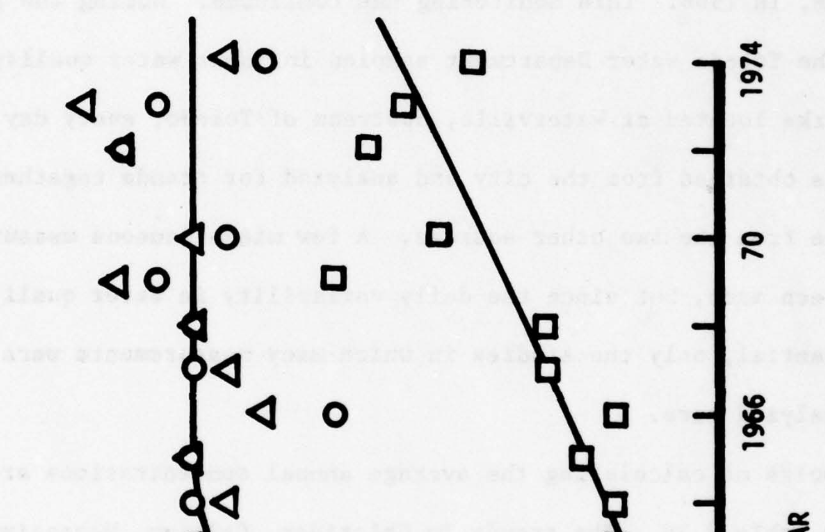

Fig. 2-24 PERCENTAGE OF PHOSPHOROUS IN FERTILIZER

on the water quality of the rivers draining into Lake Erie. Such data for the Maumee River spans nearly 70 years. During 1906 and 1907 several water quality characteristics were measured at regular intervals, possibly daily, and surely at least once a week, by the U.S. Geological Survey. This intensive effort was part of an initial overall study of the water resources of the United States. Again the Geological Survey began making regular measurements of water quality there, on a semi-monthly basis, in 1966. This monitoring has continued. During the period 1917-1941, the Toledo Water Department sampled influent water quality at the water works located at Waterville, upstream of Toledo, every day. This data was obtained from the city and analyzed for trends together with the data from the two other sources. A few miscellaneous measurements have been made, but since the daily variability in water quality can be substantial, only the studies in which many measurements were made have been analyzed here.

The results of calculating the average annual concentrations are displayed in Table 2.39. The trends in Chlorides, Calcium, Magnesium, and Residue on Evaporation are plotted in Figures 2.25 and 2.26. The average chloride concentration in the period 1966-1973 of 22.81 mg/ℓ represented a 38% increase over the average of 16.57 mg/ℓ for 1917-1941. On the other hand the average residue on evaporation decreased from 332 mg/ℓ to 314 mg/ℓ from 1917-1920 to 1967-1972. This latter trend may not be significant. Based on the standard deviation of the measurements, there is approximately an 85% chance that the samples included in the 1917-1924 period are drawn from the same population as the 1966-1973 samples. On the 5% confidence level no trend exists in that parameter.

Table 2.39

WATER QUALITY DATA FOR THE MAUMEE RIVER
AT WATERVILLE (mg/ℓ)

	Chlorine as Chlorides	Ca	Mg	Residue on Evaporation	Nitrates (NO_3)	Free Ammonia	Albuminoid Ammonia	Nitrites
1917	18.6	68.8	11.6	328	5.62	.27	.44	Trace
18	25.7	66.5	14.2	337	8.24	.03	.38	"
19	19.3	67.2	15.6	367	9.65	.03	.30	"
1920	17.6	69.1	14.2	359	7.79	.02	.27	"
21	15.8	62.2	13.5	325	9.03	.02	.30	"
22	16.8	58.8	14.0	318	6.78	.01	.28	"
23	16.4	61.2	14.8	331	7.44	.01	.31	"
24	15.4	60.0	14.9	287	7.53	.02	.35	"
25	20.7	64.8	17.4					
26	12.8	64.0	15.0					
27	12.7	58.3	13.8					
28	14.9	60.3	15.4					
29	9.6	54.5	10.9					
1930	21.3	56.2	19.5					
31	26.6	61.8	18.3					
32	13.6	60.4	15.1					
33	13.4	57.5	15.9					
34	21.9	58.5	21.5					
35	16.7	64.0	18.0					
36	16.7	71.2	21.0					
37	10.5	57.9	16.1					
38	12.8	58.4	17.7					
39	14.5	62.4	16.8					
1940	14.6	60.0	17.2					
41	15.4	65.5	17.9					

[Avg NO_3 = 7.75

[Avg residue = 332, σ = 24.68

[Avg Cl 1917-1941 = 16.57]

Table 2.39 (contd)

WATER QUALITY DATA FOR THE MAUMEE RIVER AT WATERVILLE (mg/ℓ)

	Chlorine as Chlorides	Ca	Mg	Residue on Evaporation	Nitrates (NO_3)	Free Ammonia	Albuminoid Ammonia	Nitrites
1950	7.0	48.4	12.4	224	8.6			
51	7.7	52.6	12.7	238	10.7	[Avg. NO_3 = 9.65]		
1966	22.8			338				
67	20.3			307	22.3			
68	13.4			240	17.4			
69	17.2			302	22.7			
1970	27.3			334	25.7			
71	34.3			377	30.2			
72	27.5			325	31.5	[Avg. NO_3 = 25.0]		
73	19.7			288				

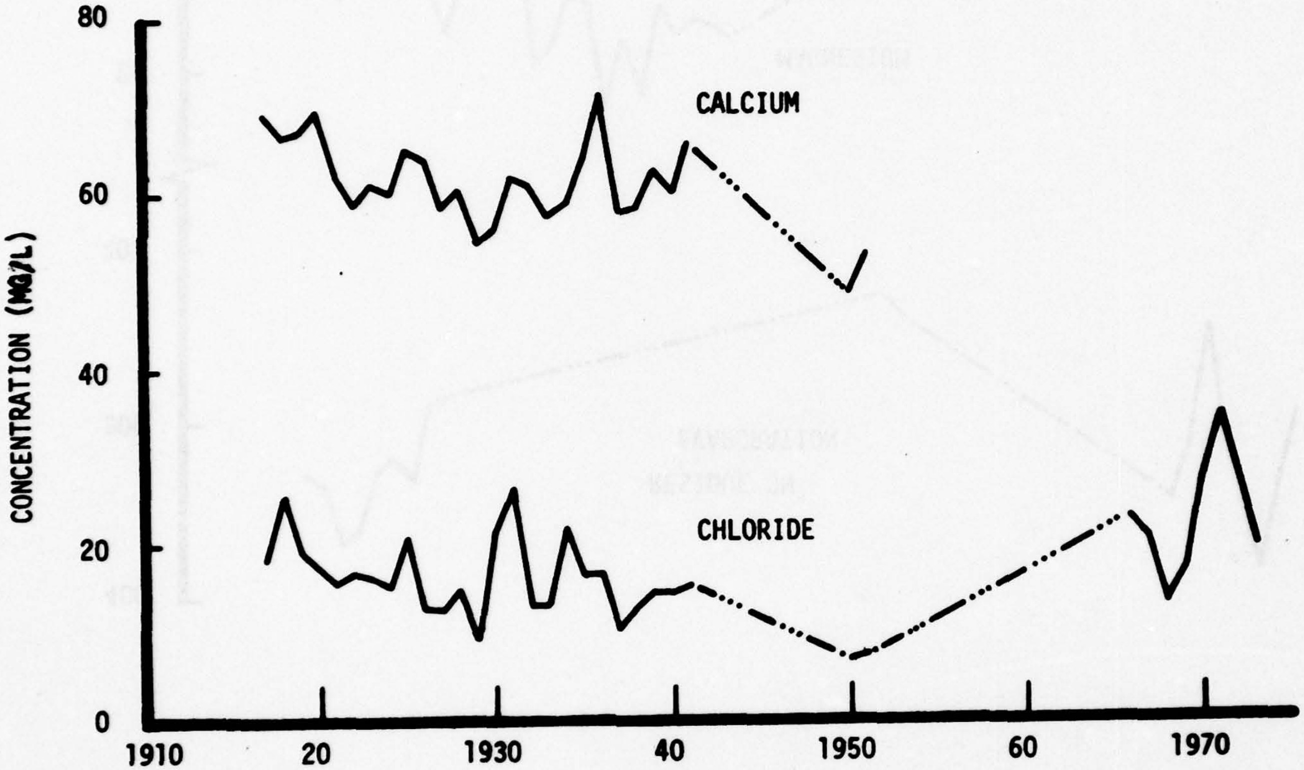

Fig. 2-25. CALCIUM AND CHLORIDE IN THE MAUMEE RIVER AT WATERVILLE

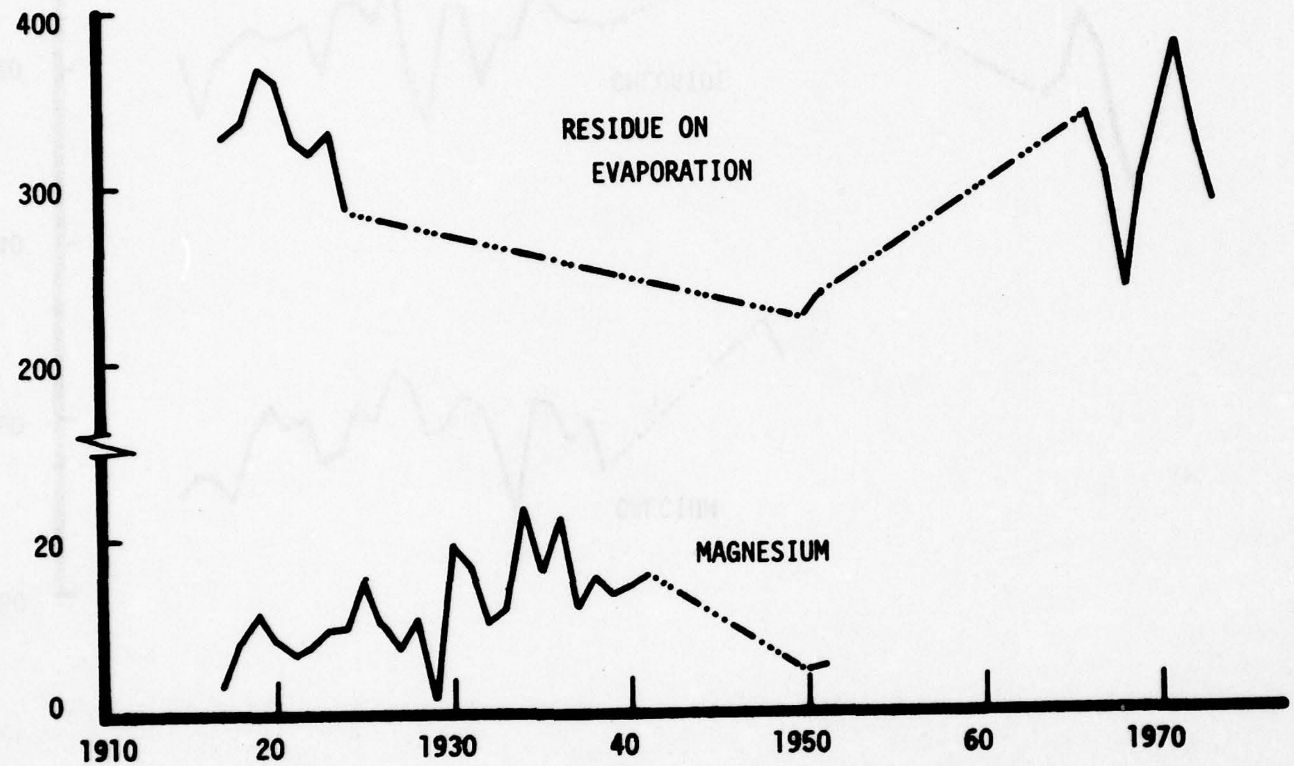

Fig. 2-26. RESIDUE ON EVAPORATION AND MG IN MAUMEE RIVER AT WATERVILLE

The only remarkable change in a water quality characteristic is a dramatic rise in NO_3 concentration. Recently the rate of increase has been somewhat greater than 9% per year as compared to slightly less than 9% annually for the increase in nitrogen fertilizer application. A comparison of these trends is depicted in Figure 2.27, where average annual nitrate concentrations measured at Waterville, above Toledo, are plotted. The amount of nitrogen applied in commercial fertilizers in the Western Basin in Ohio, taken from Table 2.27A, is also plotted.

The coincidence of the rates of increase and the similarity of the shapes of the two curves give an immediate impression of cause and effect. It could readily be assumed that the much greater present-day nitrate concentrations in the Maumee River are due primarily to rising use of nitrogen in fertilizers in that basin.

On the other hand, it could be argued that it is difficult to establish precise relationships between the application of chemical fertilizers to the soil and changes in local surface and ground water quality. This is due to (1) the difficulty in determining the effects of other inputs, such as feedlot runoff, domestic waste, and forest runoff, not to mention runoff from unmanaged land, direct precipitation, and natural soil processes; (2) an incomplete understanding of the effects of land management on runoff quality; (3) an incomplete understanding of the nitrogen cycle in soils; and (4) the difficulty in accounting for naturally occurring random variations in erosion and runoff rates. A number of experimental studies have been performed under various conditions and these have resulted in different conclusions. One study concluded that ".... the intensity of fertilizer use, in total

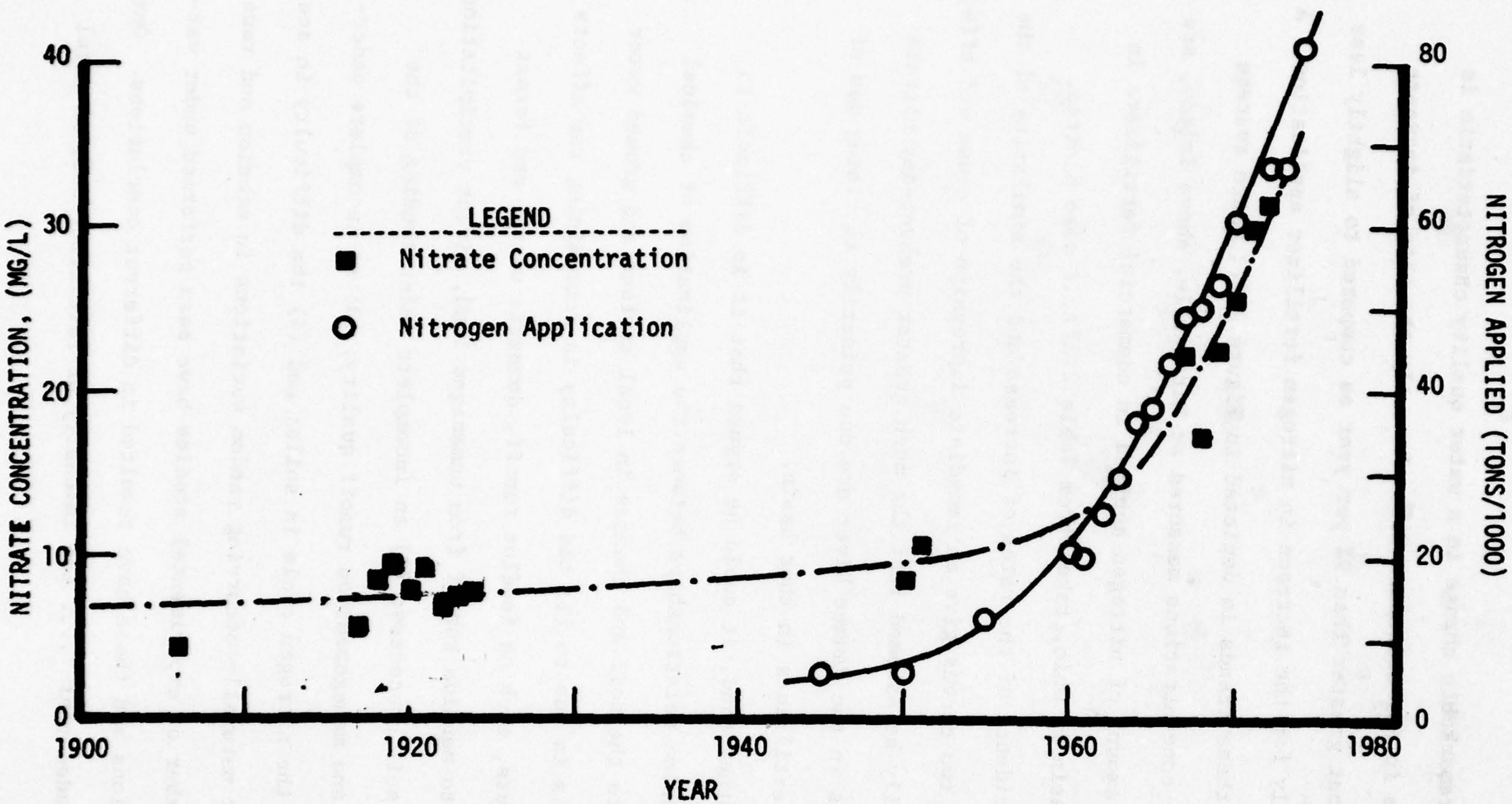

Fig. 2-27. NITRATE CONCENTRATION IN THE MAUMEE RIVER AND NITROGEN APPLICATION IN COMMERCIAL BERTILIZER

terms or as fertilizer N only, has very little relation to nutrients carried in the (draining) stream, either in concentration or total flow"(74). This statement neglects the concepts of mass flows of nitrogen as well as the processes of transformation of nitrogen in the soil. Whereas phosphorous is strongly absorbed by the soil and relatively little drains out, nitrogen is transformed by soil bacteria and generally passes through the soil column, flowing out as nitrate. It is therefore logical that nitrogen applied in excess of plant and crop requirements would ultimately make its way to a drainage course.

Loehr has written that "... the yields of total nitrogen from precipitation, forest land, crop land, land receiving manure, surface irrigation return flows, and urban land drainage span a comparable range" (75). For example, precipitation inputs range between 6 and 10 kg/ha/yr (5 to 9 lbs/acre/yr). Maximum loading rates for forest land and cropland are about 12 kg/ha/yr (11 lbs/acre/yr). Surface irrigation return flows may yield 30 kg/ha/yr (27 lbs/acre/yr).

On the other hand, considering an average flow of 4,600 cfs over the 6,400 mi watershed, a nitrate concentration of 34 mg/ℓ implies a yield of 17 lbs/acre/yr. over the whole watershed. This is on the order of the total precipitation input plus the runoff from cropland in the watershed.

Considering the long term trend, it must also be concluded that the concentration of nitrogen in precipitation has increased since the beginning of the century. Since concentrations of NO_3 in the Maumee River were, until recent years, much lower than the precipitation ranges reported by Loehr (75), such a conclusion is reasonable.

Taking into account all the factors, the simultaneous rise in nitrate concentration with nitrogen fertilizer application are very probably closely associated in a causal relationship.

Trends in Detergent Usage

The word detergent is broadly applied to the wide variety of cleansing materials used to remove soil from clothes, dishes and many other things. The two most important categories of detergents are soaps, derived from oils and fats, and synthetic detergents, called syndets, which since 1945 have been widely accepted substitutes for soap. The major advantage of syndets is that they do not form insoluble precipitates with the ions in water causing hardness. Figure 2.28 shows that in the past 25 years, syndets have come to dominate the detergent market. (68).

The basic ingredients of detergents are organic materials which have the property of being surface active in aqueous solution, and are therefore termed surface-active agents or surfactants. Marketed cleansers also contain additives designed to create a more commercially successful product. The most important additives are detergency builders which enhance the detergent properties of the active ingredients. Builders are usually sodium sulfate, sodium tripolyphosphate, sodium pyrophosphate and sodium silicate. Syndets contain from 20 to 30 per cent of surfactant and 70 to 80 percent of builder.

Products in which soap is the sole or predominant surface-active agent are considered soap products and not synthetic detergents. Synthetic detergents generally do not contain soap, although soap is used in small quantities in some products. Table 2.40 displays soap and

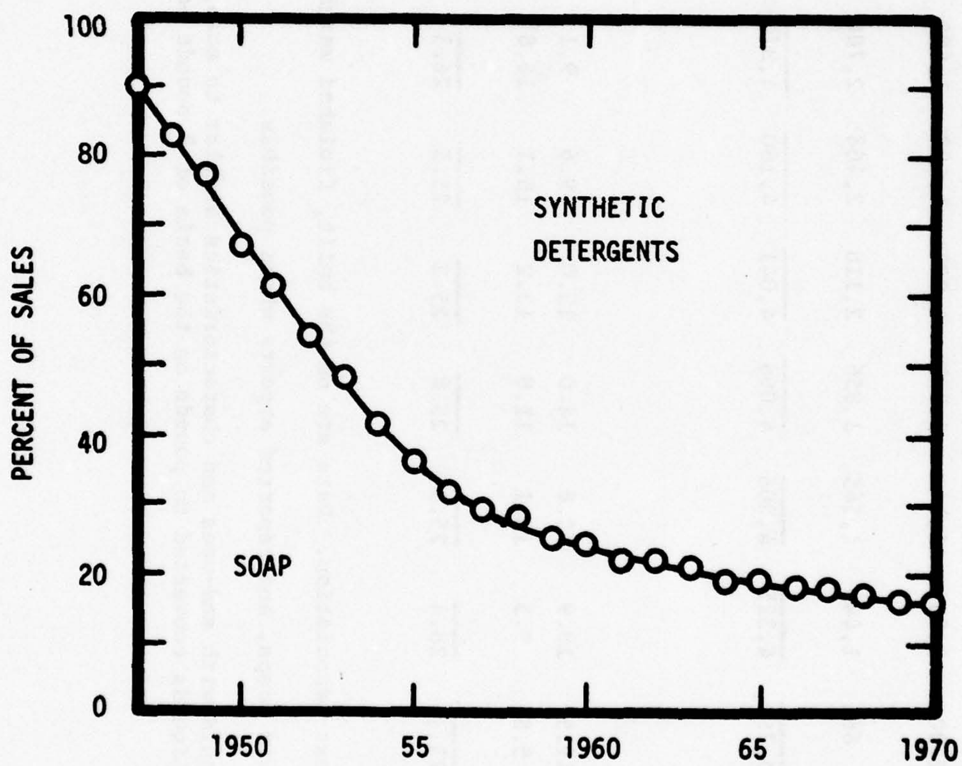

Fig. 2-28. MARKET SHARES OF DETERGENTS BY TYPE

TABLE 2.40 ESTIMATED SALES OF SOAP AND SYNTHETIC DETERGENTS[a]

	1947	48	49	1950	51	52	53	54	55	56	57	58	59
TOTAL SALES (Million Pounds)													
Soap[b] (Non-liquid)	3,512	3,088	2,905	2,882	2,441	2,210	1,923	1,692	1,590	1,540	1,430	1,370	1,250
Synthetic[e] Detergent	408	636	864	1,443	1,565	1,856	2,118	2,468	2,780	3,230	3,500	3,550	3,820
TOTAL	3,920	3,724	3,769	4,325	4,006	4,066	4,041	4,160	4,370	4,770	4,930	4,920	5,070
PER CAPITA (Pounds)													
Soap[b]	24.4	21.1	19.5	18.9	15.8	14.0	12.0	9.6	9.1	8.3	7.8	7.0	6.8
Synthetic[c] Detergent	2.8	4.3	5.8	9.5	10.1	11.8	13.2	15.1	16.8	19.1	20.3	20.3	21.5
TOTAL	27.2	25.4	25.3	28.4	25.9	25.8	25.2	25.5	26.3	28.2	28.7	28.1	28.5

a Estimates of the Soap and Detergent Association. Data are on the built, finished weight basis.

b Excludes scouring cleansers, liquid soaps, and reported exports where possible.

c Includes only those solid and liquid with end-uses and characteristics similar to soap, and excludes scouring cleaners and shampoos where possible. Liquids converted to pounds on the basis of 8 pounds per gallon.

d Preliminary

TABLE 2.40 (Continued)

	1960	61	62	63	64	65	66	67	68	69	1970[d]
TOTAL SALES (Million Pounds)											
Soap[b] (Non-liquid)	1,230	1,180	1,210	1,190	1,140	1,110	1,100	1,110	1,110	1,070	1,050
Synthetic[a] Detergent	3,940	4,110	4,420	4,540	4,730	4,870	5,000	5,200	5,350	5,490	5,650
TOTAL	5,170	5,290	5,630	5,730	5,870	5,980	6,100	6,310	6,460	6,560	6,700
PER CAPITA (Pounds)											
Soap[b]	6.8	6.4	6.5	6.3	5.9	5.7	5.6	5.6	5.5	5.3	5.1
Synthetic[c] Detergent	21.8	22.4	23.7	24.0	24.6	25.0	25.4	26.1	26.6	27.0	27.6
TOTAL	28.6	28.8	30.2	30.3	30.6	30.7	31.0	31.7	32.1	32.3	32.7

detergent sales from 1947 to 1970 as estimated by the Soap and Detergent Association.

Trends developed in Figure 2.29 and Table 2.41A are based upon the Soap and Detergent Association's estimates for per capita sales from 1947 to 1970. Unfortunately, they stopped estimating in 1970 because of their inability to cope with the increased diversification of synthetic cleaning products that were being marketed. It is reasonable to assume that the consumption of detergents is a function primarily of per capita income; a greater income would reasonably correspond with more hot water usage and a larger wardrobe, which means in general, more frequent washings. Thus, the national average figures listed in Table 2.40 were multiplied by income correction coefficients corresponding to the Lake Erie Basin region in the U. S. The coefficients were calculated as indicated in the Appendix (p.178).

It also seems reasonable to assume that sales figures could be equated to consumption figures without too much error, based on the assumption that cleaning products are bought as they are consumed and that there is little long-term storage or inventory spoilage.

The trend in Figure 2.30, displayed in Table 2.42A reflects the production of surfactants for use in synthetic detergents. Again, the assumption was made that all surfactants produced are used up in detergents and not stored.

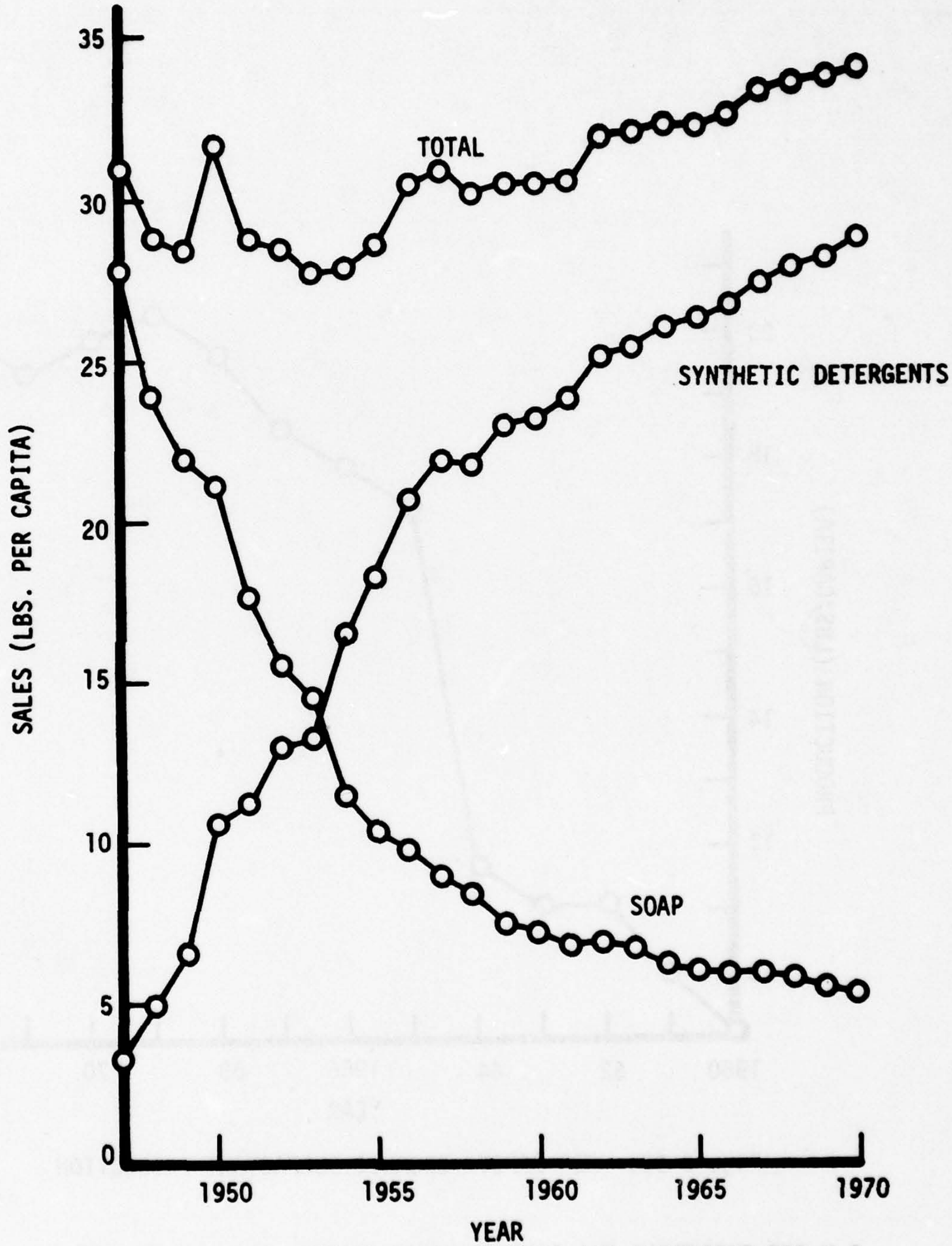

Fig. 2-29. PER CAPITA SALES OF SOAP AND DETERGENT FOR U.S. LAKE ERIE BASIN

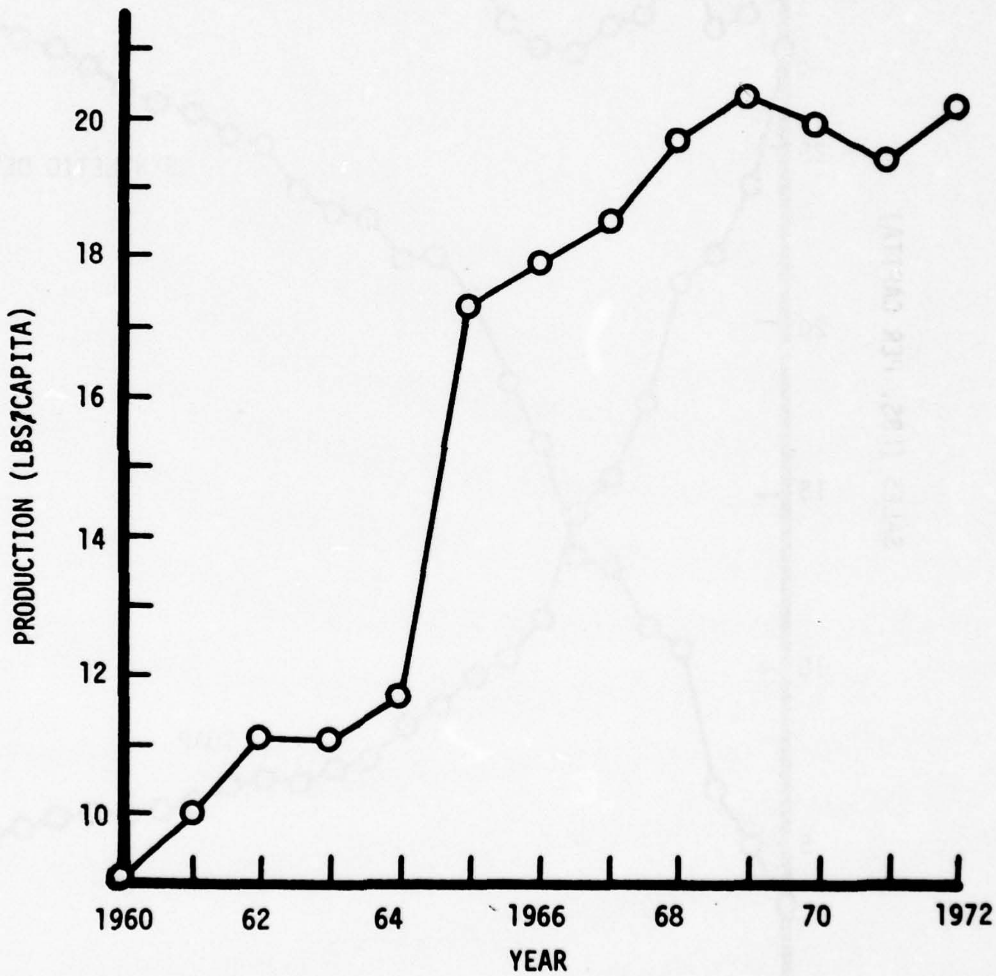

Fig. 2-30. PER CAPITA ORGANIC SURFACTANT PRODUCTION

Following a period of introduction, approximately 1947 to 1956, synthetic detergents have accounted for about 80% of all detergent sales. For example, Fig.2-31 demonstrates that sales stabilized in the 1960's. By 1970 the percent share of syndet sales appeared to level off at about 84%. Per capita use of syndets through the 1960's increased at an average annual rate of approximately 2% with extremes of 0.9% in 1960 and 5.5% in 1962. This corresponds to annual per capita growth rate for the same period of about 1% for the industry with extremes of 0.0% in 1960 and 1965 and 4.6% in 1962. The difference is explained by the continuing decline of soaps at a corresponding rate of about -3% with extremes of -7.5% in 1964 and + 1.5% in 1962 (Figures 2.31 and 2.32).

It was hoped that organic surfactant production could help to explain trends since 1970, because data were available up until 1972. Although there was a major increase in surfactant production during 1965, the period from 1966 to 1969 showed a constant growth of about 4%. After dipping slightly in 1970 and 1971, it regained the 4% growth rate in 1972. Even though the surfactant production graph corresponds to the detergent sales graph in certain periods, for example 1960-64, and 1965-69, there is not enough of a correlation to estimate detergent sales after 1970 from just the surfactant production record.

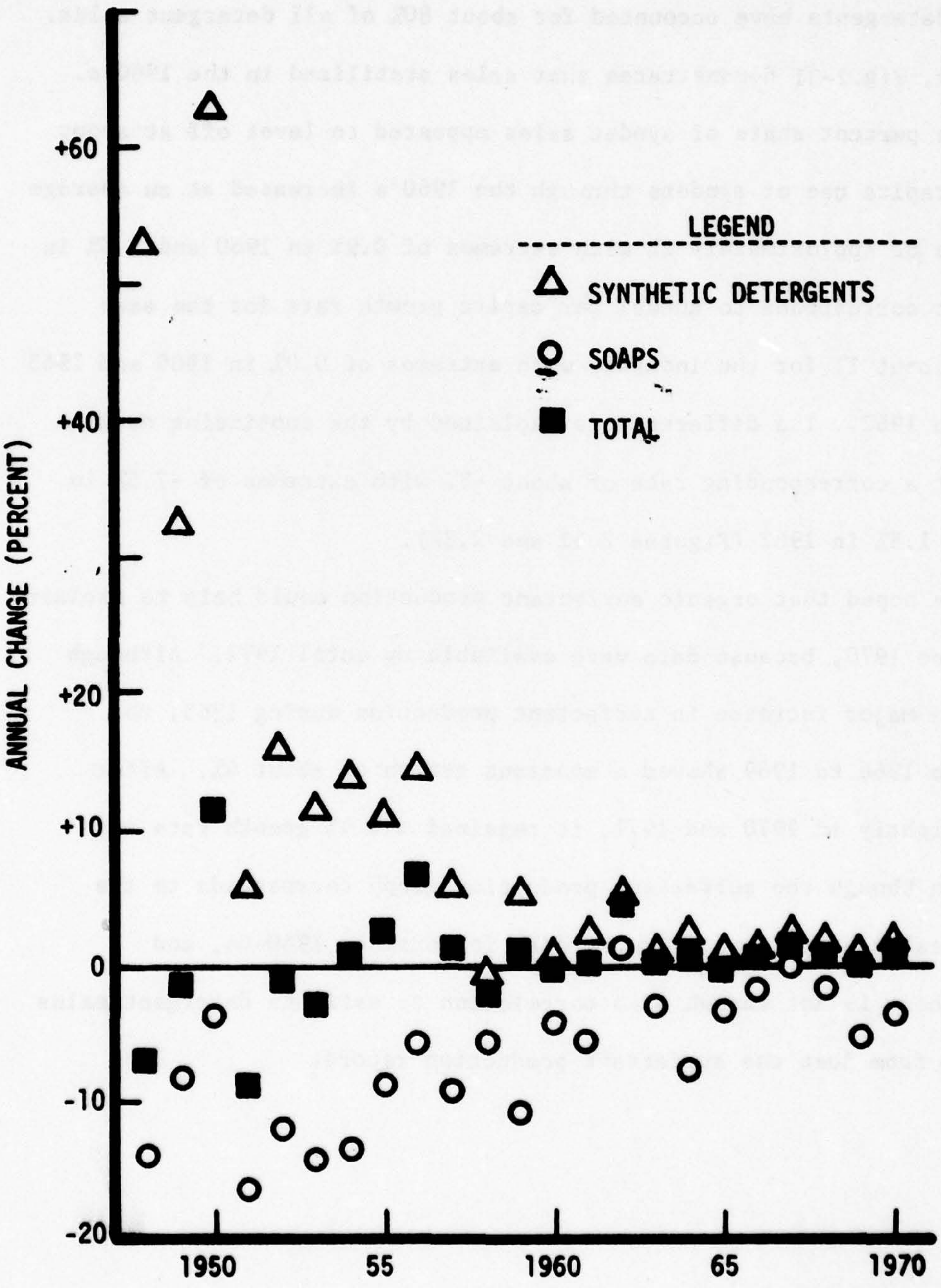

Fig. 2-31. ANNUAL CHANGE IN PER CAPITA SALES OF SOAPS AND DETERGENTS

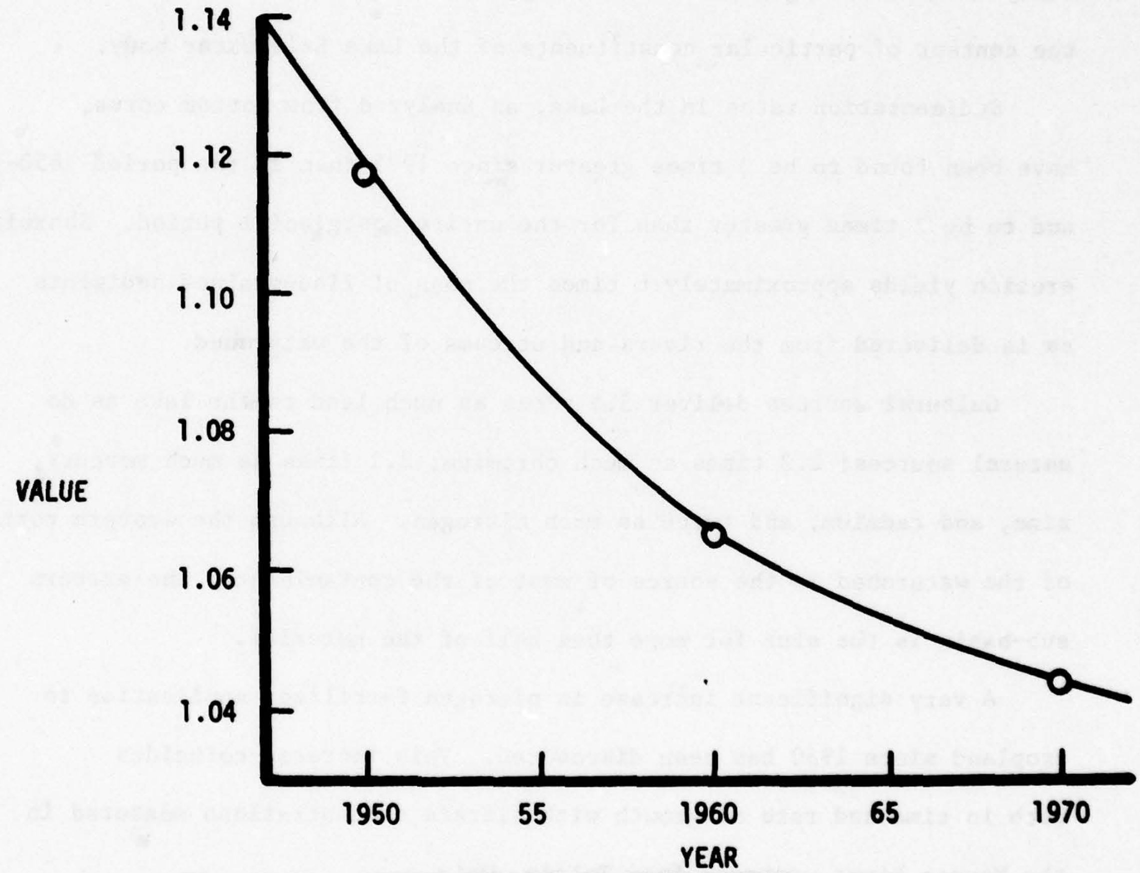

Fig. 2-32. INCOME CORRECTION COEFFICIENTS

CONCLUSIONS

A review and analysis of the existing literature on the water quality of Lake Erie was carried out as part of the Lake Erie Wastewater Management Study of the U.S. Army Corps of Engineers. The objective was to study trends and magnitudes of loadings of certain contaminants and of the content of particular constituents of the Lake Erie water body.

Sedimentation rates in the Lake, as analyzed from bottom cores, have been found to be 3 times greater since 1935 than in the period 1850-1935 and to be 7 times greater than for the entire postglacial period. Shoreline erosion yields approximately 6 times the mass of fine-grained sediments as is delivered from the rivers and streams of the watershed.

Cultural sources deliver 3.5 times as much lead to the lake as do natural sources; 2.3 times as much chromium; 2.1 times as much mercury, zinc, and cadmium; and twice as much nitrogen. Although the western portion of the watershed is the source of most of the contaminants, the eastern sub-basin is the sink for more than half of the material.

A very significant increase in nitrogen fertilizer application to cropland since 1950 has been discovered. This increase coincides both in time and rate of growth with nitrate concentrations measured in the Maumee River upstream from Toledo, Ohio.

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APPENDIX

Table 2.6A

LAKE ERIE BASIN POPULATION

Western Sub-basin, United States

State, County	Population, Year 1890	1900	1910	1920	1930	1940	1950	1960	1970
Indiana									
Adams	16,145	17,786	17,472	16,402	15,966	17,003	17,914	19,714	21,494
Allen	53,351	61,816	74,709	91,442	117,394	124,067	146,978	185,757	222,177
DeKalb	24,307	25,711	25,054	25,600	24,911	24,756	26,023	28,271	30,557
Noble	2,336	2,353	2,401	2,247	2,240	2,278	2,508	2,816	3,090
Steuben	4,826	5,073	4,758	4,453	4,462	4,580	5,696	5,728	6,602
Michigan									
Hillsdale	15,330	14,933	14,837	14,081	13,709	14,546	15,958	17,371	18,300
Ingham	*	*	*	*	*	*	*	*	*
Jackson	2,252	2,411	2,671	3,627	4,615	4,655	5,396	6,600	7,121
LaPeer	9,738	9,214	8,678	8,594	9,449	10,705	11,931	13,975	17,245
Lenawee	48,448	48,406	47,907	47,767	49,849	53,110	64,629	77,789	80,220
Livingston	10,429	9,832	8,868	8,761	9,636	10,432	13,363	19,117	29,333
Macomb	31,813	33,244	32,606	38,103	77,146	107,638	184,961	405,804	620,478
Monroe	32,337	32,754	32,917	37,115	52,485	58,620	75,666	101,120	117,625
Oakland	37,121	40,313	44,618	81,045	190,126	228,661	356,401	621,233	810,622
Sanilac	19,553	21,033	20,358	18,742	16,651	18,068	18,502	19,388	20,703
St. Clair	52,105	55,228	52,341	58,009	67,563	76,222	91,599	107,201	118,776
Washtenaw	42,210	47,761	44,714	49,520	65,530	80,810	134,606	172,440	230,128
Wayne	257,114	348,793	531,591	1,177,645	1,888,946	2,015,623	2,435,235	2,666,297	2,642,348
Ohio									
Allen	40,644	47,976	56,580	68,223	69,419	73,303	88,183	103,691	110,849
Auglaize	28,100	31,192	31,246	29,527	28,034	28,037	30,637	36,147	38,249
Defiance	25,769	26,387	24,498	24,549	22,714	24,367	25,925	31,508	36,924

*not significant

Table 2.6A(,tinued)

State, County	Population, Year 1890	1900	1910	1920	1930	1940	1950	1960	1970
Ohio									
Fulton	22,023	22,801	23,914	23,445	23,477	23,626	25,580	29,301	32,764
Geauga	13,489	14,744	14,670	15,036	15,414	19,430	26,646	47,573	62,740
Hancock	42,563	41,993	37,860	38,394	40,404	40,793	44,280	53,686	60,775
Hardin	1,447	1,559	1,520	1,458	1,382	1,353	1,434	1,482	1,518
Henry	25,080	27,282	25,119	23,362	22,524	22,756	22,423	25,392	26,748
Lucas	102,296	153,559	192,728	275,721	347,709	344,333	395,551	456,931	478,966
Mercer	13,610	14,011	13,768	13,436	12,548	13,128	14,156	16,280	17,642
Ottawa	21,974	22,213	22,360	22,193	24,109	24,360	29,469	35,323	36,168
Paulding	25,932	27,528	22,730	18,736	15,301	15,527	15,047	16,792	19,062
Putnam	30,188	32,525	29,972	27,751	25,074	25,016	25,248	28,331	30,899
Sandusky	12,247	13,724	14,068	14,844	15,892	16,406	18,446	22,594	24,048
Seneca	3,270	3,293	3,394	3,454	3,835	3,880	4,238	4,746	4,814
VanWert	29,671	30,394	29,119	28,210	26,273	26,759	26,971	28,840	28,939
Williams	24,897	24,963	25,198	24,627	24,316	25,510	26,202	29,968	33,357
Wood	44,392	51,555	46,330	44,892	50,320	51,796	59,605	72,596	88,864
Wyandot	2,172	2,113	2,076	1,948	1,904	1,922	1,979	2,165	2,148
Total	1,169,179	1,366,473	1,583,650	2,382,959	3,381,327	3,634,076	4,489,386	5,513,967	6,132,293

Table 2.7 A

LAKE ERIE BASIN POPULATION

Central Sub-basin, United States

State, County	Population, Year 1890	1900	1910	1920	1930	1940	1950	1960	1970
Ohio									
Ashland	4,445	4,237	4,595	4,925	5,373	5,957	5,754	7,754	8,639
Ashtabula	41,472	48,876	56,570	62,268	64,943	65,240	74,760	88,414	92,452
Crawford	21,284	22,610	22,690	24,036	23,563	23,714	25,825	31,183	33,629
Cuyahoga	309,970	439,120	637,425	943,495	1,201,455	1,217,250	1,389,532	1,647,895	1,701,640
Erie	35,462	37,650	38,327	39,789	42,133	43,201	52,565	68,000	74,409
Hardin	13,023	14,035	13,684	13,126	12,436	12,177	12,902	13,335	13,660
Huron	31,949	32,330	34,206	32,424	33,700	34,800	39,353	47,326	49,307
Lake	18,235	21,680	22,927	28,667	41,674	50,020	75,979	148,700	196,126
Lorain	40,295	54,857	76,037	90,612	109,206	112,390	148,162	217,500	255,612
Marion	8,242	9,559	11,324	14,001	15,140	14,966	16,653	20,073	21,132
Medina	10,871	10,979	11,799	13,034	14,839	16,517	20,209	32,658	41,442
Portage	13,934	14,623	15,154	8,135	21,341	23,330	31,977	45,899	61,626
Sandusky	18,370	20,587	21,103	22,265	23,839	24,608	27,668	33,892	36,072
Seneca	37,600	37,870	39,027	39,722	44,106	44,619	48,740	54,580	55,356
Summit	43,271	57,372	86,602	228,852	235,305	271,524	328,026	410,855	440,187
Trumbull	4,237	4,659	5,277	8,392	12,306	13,232	15,892	20,853	23,157
Wyandot	19,550	19,013	18,684	17,533	17,132	17,296	17,807	19,483	19,328
Pennsylvania									
Erie	11,620	13,294	15,595	20,727	23,662	24,420	29,617	33,842	34,811
Total	683,830	863,351	1,131,026	1,612,003	1,942,153	2,015,261	2,361,421	2,942,242	3,158,585

Table 2.8A

LAKE ERIE BASIN POPULATION

Eastern Sub-basin, United States

State, County	*Population, Year*								
	1890	*1900*	*1910*	*1920*	*1930*	*1940*	*1950*	*1960*	*1970*
New York									
Cattaragus	9,130	9,846	9,888	10,698	10,860	10,898	11,685	12,028	12,119
Chautauqua	25,067	29,438	35,042	38,449	42,152	41,193	45,063	48,459	48,309
Erie	161,491	216,843	264,493	317,344	381,204	399,189	449,619	532,344	551,707
Wyoming	6,239	6,083	6,376	6,063	5,753	6,279	6,564	6,959	7,372
Pennsylvania									
Crawford	3,266	3,182	3,078	3,033	3,149	3,582	2,947	3,898	3,924
Erie	65,847	75,332	88,370	117,455	134,087	138,380	167,832	191,772	197,263
Total	280,441	340,724	407,247	493,042	577,205	599,521	683,710	795,460	820,694

Table 2.9A

LAKE ERIE BASIN POPULATION

Western Sub-basin, Canada

	Population, Year									
County	1901	1911	1921	1931	1941	1951	1956	1961	1966	1971
Elgin	2,179	2,216	2,249	2,172	2,308	2,776	2,956	3,143	3,096	3,308
Essex	57,569	66,196	100,524	156,584	170,745	212,807	241,963	253,054	275,304	293,405
Huron	592	486	449	444	426	417	398	388	385	398
Kent	54,334	53,195	55,052	59,722	63,029	75,172	81,094	84,956	91,586	91,349
Lambton	45,283	41,137	42,935	44,098	44,998	62,938	74,361	83,964	89,271	92,335
Middlesex	75,110	81,233	91,596	103,164	111,937	144,024	169,681	200,733	227,145	253,702
Oxford	26,622	26,054	25,719	26,304	28,036	32,350	35,875	38,775	41,810	43,865
Perth	31,222	31,856	33,969	34,451	33,034	35,246	43,793	38,656	40,523	42,909
Total	292,911	302,373	352,493	426,939	454,513	565,730	650,121	703,669	769,120	821,271

Table 2.10A

LAKE ERIE BASIN POPULATION

Central Sub-basin, Canada

County	Population, Year 1901	1911	1921	1931	1941	1951	1956	1961	1966	1971
Elgin	41,407	42,096	42,735	41,264	43,843	52,742	56,158	59,719	58,816	62,846
Essex	1,175	1,351	2,052	3,196	3,485	4,343	4,938	5,164	5,618	5,988
Kent	2,860	2,800	2,898	3,143	3,317	3,956	4,268	4,471	4,820	4,808
Middlesex	3,953	4,275	4,821	5,430	5,891	7,580	8,931	10,565	11,955	13,353
Norfolk	1,457	1,356	1,318	1,568	1,781	2,135	2,306	2,524	2,529	2,683
Oxford	9,681	9,474	9,352	9,565	10,195	11,764	13,046	14,100	15,204	15,951
Perth	3,673	3,748	3,996	4,053	3,886	4,147	4,379	4,548	4,767	5,048
Total	64,206	65,100	67,172	68,219	72,398	86,667	94,026	101,091	103,709	110,677

Table 2.11A

LAKE ERIE BASIN POPULATION

Eastern Sub-basin, Canada

County	Population, Year									
	1901	1911	1921	1931	1941	1951	1956	1961	1966	1971
Brant	38,140	45,876	53,377	53,476	56,695	72,857	77,992	83,839	90,945	91,176
Dufferin	8,131	6,618	5,756	5,212	4,890	4,817	4,858	4,807	4,909	5,242
Haldimand	17,231	17,765	17,677	17,960	18,444	20,338	22,048	23,793	25,189	26,457
Halton	236	225	213	194	187	197	226	237	279	344
Norfolk	27,690	25,755	25,048	29,791	33,831	40,573	43,816	47,951	48,049	50,980
Oxford	12,101	11,843	11,691	11,956	12,744	14,705	16,307	17,625	19,005	19,939
Perth	1,837	1,874	1,998	2,027	1,943	2,073	2,190	2,274	2,384	2,524
Waterloo	52,594	62,607	75,266	89,852	98,720	126,123	148,744	176,754	216,728	251,478
Welland	4,534	4,980	8,007	12,816	14,240	17,893	21,865	23,875	26,353	22,488
Wellington	39,053	39,916	41,135	45,297	47,083	53,488	61,441	69,735	78,749	89,692
Wentworth	4,810	4,679	5,324	4,826	5,112	6,843	9,045	10,421	11,632	12,292
Total	206,357	222,138	245,492	273,407	293,889	359,907	408,532	461,311	524,222	572,612

Table 2.12A

CANADIAN LAKE ERIE BASIN POPULATION

Interpolated to U.S. Census Years

Year	*West*	*Central*	*East*
1900	291,951	64,116	204,726
1910	301,413	65,010	220,507
1920	347,128	66,962	243,050
1930	418,836	68,114	270,478
1940	451,677	71,969	291,774
1950	553,481	85,122	352,687
1960	692,618	99,637	450,236
1970	810,565	109,247	562,589

Table 2.13A

LAKE ERIE BASIN POPULATION

United States and Canada

Year	*West*	*Central*	*East*	*Total*
1900	1,658,424	927,467	545,450	3,131,341
1910	1,885,063	1,196,036	627,754	3,708,853
1920	2,730,087	1,678,965	736,092	5,145,144
1930	3,800,163	2,010,267	847,683	6,658,113
1940	4,085,753	2,087,230	891,295	7,064,278
1950	5,042,867	2,446,543	1,036,397	8,525,807
1960	6,206,585	3,041,879	1,245,696	10,494,160
1970	6,942,858	3,267,832	1,383,283	11,593,973

Table 2.14A

LAKE HURON AND LAKE SUPERIOR BASIN POPULATION

Canadian Population

Year	*Lake Huron*	*Lake Superior*
1901	467,335	9,706
1911	483,662	40,601
1921	479,162	49,430
1931	495,929	63,183
1941	520,725	81,459
1951	590,252	102,540
1956	678,057	123,566
1961	786,433	143,123
1966	838,475	148,752
1971	906,945	142,162

Table 2.15A

UPPER GREAT LAKES POPULATION

Total United States and Canada

Year	*Lake Michigan*	*Lake Huron U.S.*	*Lake Huron Canada*	*Lake Superior U.S.*	*Lake Superior Canada*	*TOTAL*
1890	2,899,631	455,596	453,982	167,305	21,747	3,998,261
1900	3,774,634	508,711	467,783	283,157	27,663	5,061,948
1910	4,603,493	558,311	482,004	421,665	35,187	6,100,660
1920	5,493,640	628,620	479,610	470,646	48,467	7,120,983
1930	6,858,854	735,080	494,226	439,654	61,651	8,589,465
1940	7,176,953	814,508	518,191	444,745	79,416	9,033,813
1950	8,182,011	941,830	582,901	424,527	100,207	10,231,476
1960	9,700,598	1,198,176	763,454	448,631	138,978	12,249,837
1970	10,566,266	1,390,880	892,818	429,033	143,456	13,422,453

Table 2.16A

UPPER GREAT LAKES POPULATION

Total United States and Canada

Year	*Total*	*Log*
1890	3,998,261	6.60187
1900	5,061,948	6.70432
1910	6,100,660	6.7854
1920	7,120,983	6.8525
1930	8,589,465	6.93397
1940	9,033,813	6.9559
1950	10,231,467	7.0099
1960	12,249,837	7.088
1970	13,422,453	7.1278

Table 2.17A

URBAN POPULATION, UNITED STATES
(x 1000)

	1900	1910	1920	1930	1940	1950	1960	1970
WESTERN BASIN								
Indiana	47	64	84	107	111	131	166	204
Michigan	379	994	1,541	2,113	2,234	2,940	3,750	4,257
Ohio	227	280	376	436	440	542	668	750
Subtotal	653	1,338	2,001	2,656	2,785	3,613	4,584	5,211
CENTRAL BASIN								
Ohio	576	836	1,312	1,643	1,688	1,878	2,606	2,796
Penn.	22	28	37	45	46	56	63	64
Subtotal	598	864	1,349	1,688	1,714	2,034	2,669	2,860
EASTERN BASIN								
New York	199	253	310	362	365	429	501	523
Penn.	48	61	84	103	104	130	149	152
Subtotal	247	314	394	465	469	559	650	675
TOTAL	1,498	2,516	3,744	4,809	4,968	6,206	7,903	8,746

Table 2.19A

CHICKENS[1]
(x 1,000)

	1930	1935	1940	1945	1954	1959	1964	1969
WESTERN BASIN								
Michigan	1,256	1,294	1,677	1,317	1,109	826	696	635
Indiana	522	545	448	567	602	733	757	872
Ohio	3,725	4,039	3,203	3,627	3,363	3,296	3,497	3,949
Subtotal	5,503	5,878	5,328	5,511	5,074	4,855	4,950	5,456
CENTRAL BASIN								
Ohio	2,331	2,655	2,085	2,469	2,035	1,638	1,529	1,184
Penn.	150	148	122	135	102	84	54	41
Subtotal	2,481	2,803	2,207	2,604	2,137	1,722	1,583	1,225
EASTERN BASIN								
Penn.	88	84	70	82	60	51	34	28
N.Y.	853	872	701	793	589	453	445	461
Subtotal	941	956	771	875	649	504	479	489
TOTAL	8,925	9,637	8,306	8,990	7,860	7,081	7,012	7,170

[1] All chickens on hand over 4 months old.

Table 2.20A

HOGS AND PIGS
(x 1000)

	1930	1935	1940	1945	1954	1959	1964	1969
WESTERN BASIN								
Michigan	132	85	95	115	110	132	96	89
Indiana	131	82	72	91	95	120	102	116
Ohio	602	432	358	473	458	528	471	479
Subtotal	865	599	525	679	663	780	669	684
CENTRAL BASIN								
Ohio	262	199	191	240	244	257	206	199
Penn.	4	4	4	6	4	3	2	1
Subtotal	266	203	195	246	248	260	208	200
EASTERN BASIN								
Penn.	3	2	2	3	2	2	1	1
N.Y.	15	15	17	19	17	14	7	5
Subtotal	18	17	19	22	19	16	8	6
TOTAL	1,149	819	739	947	930	1,056	885	890

Table 2.21A

ALL CATTLE
(x 1000)

	1930	1935	1940	1945	1954	1959	1964	1969
WESTERN BASIN								
Michigan	104	120	122	148	139	143	145	118
Indiana	45	56	53	69	68	59	60	49
Ohio	231	291	262	320	328	329	302	253
Subtotal	380	467	437	537	535	531	507	420
CENTRAL BASIN								
Ohio	200	245	216	249	270	237	220	297
Penn.	22	24	23	27	26	24	23	20
Subtotal	222	269	239	276	296	261	243	317
EASTERN BASIN								
Penn.	12	13	12	15	14	12	13	10
N.Y.	90	95	80	92	118	103	99	90
Subtotal	102	108	92	107	132	115	112	100
TOTAL	704	844	768	920	963	907	862	837

Table 2.22A

HARVESTED CROPLAND[1]

(X1000 Acres)

	1930	1935	1940[2]	1945[2]	1954	1959	1964	1969
WESTERN BASIN								
Michigan	749	806	761	845	829	817	738	614
Indiana	369	383	378	418	417	417	393	353
Ohio	2,334	2,360	2,362	2,603	2,565	2,631	2,595	2,499
Sub Total	3,452	3,549	3,501	3,866	3,811	3,865	3,725	3,466
CENTRAL BASIN								
Ohio	1,329	1,471	1,426	1,545	1,399	1,285	1,238	1,001
Pa.	87	89	77	84	62	54	53	43
Sub Total	1,416	1,560	1,503	1,629	1,461	1,339	1,291	1,044
EASTERN BASIN								
Pa.	49	50	43	48	36	30	31	26
N.Y.	362	366	346	371	282	245	239	196
Sub Total	411	416	389	419	318	275	270	222
TOTAL	5,279	5,525	5,393	5,914	5,590	5,479	5,286	4,732

[1] Cropland Harvested - The land from which cultivated crops were harvested; land from which hay (including wild hay) was cut; and land in small fruits, orchards, vineyards, nurseries and greenhouses.

[2] Includes land representing crop failure. Crop failure land is consistently less than 1% of harvested cropland.

Table 2.23A

OHIO FERTILIZER SALES DATA
(tons total fertilizer)[33]

	State Total	West & Central	%	West	%	Central	%
7/1/65-6/30/66	1,304,929	490,314	37.5	326,807	25.0	163,507	12.5
7/1/67-6/30/68	1,365,808	553,223	40.5	376,733	27.5	176,490	12.9
7/1/69-6/30/70	1,395,788	561,397	40.2	388,715	27.8	172,682	12.4
7/1/70-6/30/71	1,605,356	648,630	40.5	446,810	27.8	201,820	12.6
7/1/71-6/30/72	1,617,049	623,022	38.5	427,102	26.4	195,920	12.1
7/1/72-6/30/73	1,539,038	609,335	39.6	424,823	27.6	184,512	12.0
7/1/73-6/30/74	1,817,098	762,777	41.9	538,908	29.6	223,869	12.3

Table 2.24A

PERCENTAGE OF STATE TOTAL FERTILIZER USE CONSUMED IN THE LAKE ERIE BASIN REGION OF EACH STATE

	1950	1955	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
WESTERN BASIN																	
Michigan	12.3	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.1	12.1	12.1	12.1	12.1	12.1
Indiana	3.4	3.3	3.2	3.2	3.2	3.1	3.1	3.1	3.0	3.0	3.0	3.0	3.0	2.9	2.9	2.9	2.8
Ohio	19.8	21.6	23.4	23.8	24.2	24.5	24.9	25.2	25.6	26.0	26.4	26.7	27.0	27.4	27.8	28.2	28.5
CENTRAL BASIN																	
Ohio	14.6	14.1	13.5	13.4	13.3	13.2	13.1	13.0	12.9	12.7	12.6	12.5	12.4	12.3	12.2	12.1	12.0
Penn.	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9
EASTERN BASIN																	
Penn.	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
N.Y.	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9

Table 2.25A

TOTAL FERTILIZERS USED (TONS)

	1950	1955	1960	1961	1962	1963	1964	1965
WESTERN BASIN								
Michigan	58,362	77,909	81,797	88,807	82,159	99,321	100,261	94,049
Indiana	27,148	38,039	36,872	35,683	38,247	42,329	48,057	50,574
Ohio	179,513	234,433	254,299	219,287	251,714	284,846	304,719	307,437
Subtotal	265,023	350,381	372,968	343,777	372,120	426,496	453,037	452,060
CENTRAL BASIN								
Ohio	132,368	153,033	146,711	123,464	138,339	153,468	160,314	158,598
Penn.	8,849	9,290	8,018	7,748	7,335	7,259	7,596	6,642
Subtotal	141,217	162,323	154,729	131,212	145,674	160,727	167,910	165,240
EASTERN BASIN								
Penn.	5,688	5,717	5,345	5,165	4,668	4,619	4,834	4,649
N.Y.	8,519	8,193	7,107	7,092	6,456	6,683	6,975	6,932
Subtotal	14,207	13,910	12,452	12,257	11,124	11,302	11,809	11,581
TOTAL	420,447	526,614	540,149	487,246	528,918	598,525	632,756	628,881

	1966	1967	1968	1969	1970	1972	1973	1974
WESTERN BASIN								
Michigan	96,085	101,520	101,126	96,512	105,228	114,050	108,479	122,936
Indiana	55,940	60,457	56,785	55,530	59,203	54,142	59,263	63,590
Ohio	334,062	370,533	362,415	361,854	379,191	421,752	437,544	518,190
Subtotal	486,087	532,510	520,326	513,896	543,622	589,944	605,286	704,716
CENTRAL BASIN								
Ohio	168,336	180,991	172,971	169,407	174,147	185,085	187,741	218,185
Penn.	6,974	6,832	6,442	6,524	6,117	5,972	6,132	6,404
Subtotal	175,310	187,823	179,413	175,931	180,264	191,057	193,873	224,589
EASTERN BASIN								
Penn.	4,882	4,782	4,509	4,567	4,078	3,981	4,088	4,269
N.Y.	6,515	6,502	6,437	6,306	6,132	5,621	5,646	6,078
Subtotal	11,397	11,284	10,946	10,873	10,210	9,602	9,734	10,347
TOTAL	672,794	731,617	710,685	700,700	734,096	790,603	808,893	939,652

Table 2.26A

PHOSPHORUS USED (TONS)

	1950	1955	1960	1961	1962	1963	1964	1965
WESTERN BASIN								
Michigan	3,512	4,790	5,271	5,690	5,303	6,527	6,807	6,427
Indiana	1,422	2,252	2,220	2,119	2,224	2,593	2,877	2,992
Ohio	9,821	13,571	15,872	13,541	15,891	18,649	19,615	20,132
Subtotal	14,755	20,613	23,363	21,530	23,418	27,769	29,299	29,551
CENTRAL BASIN								
Ohio	7,242	8,859	9,157	7,810	8,733	10,124	10,320	10,386
Penn.	505	473	418	402	383	390	413	366
Subtotal	7,747	9,332	9,575	8,212	9,116	10,514	10,733	10,752
EASTERN BASIN								
Penn.	325	291	279	268	244	248	263	256
N.Y.	493	400	361	367	334	351	363	367
Subtotal	818	691	640	635	578	599	626	623
TOTAL	23,320	30,636	33,578	30,377	33,112	38,882	40,658	40,926

	1966	1967	1968	1969	1970	1972	1973	1974
WESTERN BASIN								
Michigan	5,196	6,918	6,677	6,385	6,900	7,710	7,266	7,688
Indiana	3,160	3,737	3,481	3,270	3,193	3,086	3,292	3,519
Ohio	21,319	24,001	23,678	24,297	24,899	28,442	29,656	33,165
Subtotal	29,675	34,656	33,836	33,952	34,992	39,238	40,214	44,372
CENTRAL BASIN								
Ohio	10,743	11,724	11,301	11,375	11,435	12,482	12,725	13,964
Penn.	375	368	359	367	356	339	373	362
Subtotal	11,118	12,092	11,660	11,742	11,791	12,821	13,098	14,326
EASTERN BASIN								
Penn.	263	258	251	255	237	226	249	241
N.Y.	341	358	356	403	360	350	324	349
Subtotal	604	616	607	658	597	576	573	590
TOTAL	41,397	47,364	46,103	46,552	47,380	52,635	53,885	59,288

Table 2.27A

NITROGEN USED (TONS)

	1950	1955	1960	1961	1962	1963	1964	1965
WESTERN BASIN								
Michigan	1,658	4,456	7,101	8,830	8,678	10,227	11,770	11,301
Indiana	896	2,600	4,242	4,486	5,604	6,130	7,124	8,451
Ohio	5,469	12,454	20,655	19,762	25,362	29,761	36,374	38,275
Subtotal	8,023	19,510	31,998	33,078	39,644	46,118	55,268	58,027
CENTRAL BASIN								
Ohio	4,033	8,129	11,916	11,127	13,939	16,034	19,137	19,745
Penn.	289	485	513	511	510	573	611	585
Subtotal	4,322	8,614	12,429	11,638	14,449	16,607	19,148	20 330
EASTERN BASIN								
Penn.	186	298	342	341	325	365	389	410
N.Y.	335	538	546	564	512	574	633	637
Subtotal	521	836	888	905	837	939	1,022	1,047
TOTAL	12,866	28,960	45,315	45,621	54,930	63,664	76,038	79,404

	1966	1967	1968	1969	1970	1972	1973	1974
WESTERN BASIN								
Michigan	12,084	13,035	13,951	13,490	16,854	18,603	17,045	18,750
Indiana	9,723	9,964	9,733	9,890	10,302	9,868	9,500	9,916
Ohio	43,667	49,359	50,704	53,257	60,936	67,364	67,069	82,195
Subtotal	65,474	72,358	74,388	76,637	88,092	95,835	93,614	110,861
CENTRAL BASIN								
Ohio	22,004	24,110	24,200	24,933	27,985	29,563	28,778	34,608
Penn.	625	702	683	753	747	685	819	792
Subtotal	22,629	24,812	24,883	25,686	28,732	30,248	29,597	35,400
EASTERN BASIN								
Penn.	438	492	478	527	498	457	546	528
N.Y.	593	663	745	723	700	694	882	781
Subtotal	1,031	1,155	1,155	1,250	1,198	1,151	1,428	1,309
TOTAL	89,134	98,325	100,426	103,573	118,022	127,234	124,639	147,570

Table 2.33A

WHEAT
(X1000 Bushels)

	1935	1940	1945	1954	1959	1964	1969
WESTERN BASIN							
Michigan	1,903	2,302	3,295	3,429	2,784	4,469	3,190
Indiana	1,180	996	1,337	1,673	1,195	2,202	1,566
Ohio	8,676	8,333	10,677	11,468	6,716	14,574	12,713
Subtotal	11,759	11,631	15,309	16,570	10,695	21,245	17,469
CENTRAL BASIN							
Ohio	4,606	5,338	7,101	6,045	4,697	6,299	4,994
Pa.	45	51	94	175	49	73	37
Subtotal	4,651	5,389	7,195	6,220	4,746	6,372	5,031
EASTERN BASIN							
Pa.	21	24	51	92	29	50	23
N.Y.	244	361	488	597	325	263	190
Subtotal	265	385	539	689	354	313	213
TOTAL	16,675	17,405	23,043	23,479	15,795	27,930	22,713

Table 2.34A

CORN
(X1000 Bushels)

	1935	1940	1945	1954	1959	1964	1969
WESTERN BASIN							
Michigan	3,764	7,742	9,100	15,811	19,188	15,846	15,712
Indiana	2,899	6,099	5,055	8,917	9,290	7,854	8,823
Ohio	22,457	40,020	31,889	50,751	55,990	52,713	60,180
Subtotal	29,120	53,861	46,044	75,479	84,468	76,413	84,715
CENTRAL BASIN							
Ohio	11,953	18,295	14,890	22,268	26,985	24,088	24,094
Pa.	271	339	301	348	349	464	477
Subtotal	12,224	18,634	15,191	22,616	27,334	24,552	24,571
EASTERN BASIN							
Pa.	132	172	133	167	149	212	207
N.Y.	238	350	155	523	480	608	731
Subtotal	370	522	288	690	629	820	938
TOTAL	41,714	73,017	61,523	98,785	112,431	101,785	110,224

Table 2.35A

SOYBEANS
(X1000 Bushels)

	1935	1940	1945	1954	1959	1964	1969
WESTERN BASIN							
Michigan	18	383	1,209	1,724	3,158	3,178	4,600
Indiana	71	770	1,173	1,773	2,407	2,553	3,543
Ohio	259	5,380	10,210	13,398	17,664	17,780	26,401
Subtotal	348	6,533	12,592	16,895	23,229	23,511	34,544
CENTRAL BASIN							
Ohio	67	1,233	3,535	4,245	5,306	6,020	9,500
Pa.	--	2	3	1	--	1	1
Subtotal	67	1,235	3,538	4,246	5,306	6,021	9,501
EASTERN BASIN							
Pa.	--	1	2	--	--	1	1
N.Y.	--	1	2	3	1	2	7
Subtotal	--	2	4	3	1	3	8
TOTAL	415	7,770	16,134	21,144	28,536	29,535	44,053

Table 2.36A

Percentage of Nitrogen in Fertilizer

	1950	1955	1960	1961	1962	1963	1964	1965
WESTERN BASIN	3.0	5.6	8.6	9.6	10.7	10.8	12.2	12.8
CENTRAL BASIN	3.1	5.3	8.0	8.9	9.9	10.3	11.4	12.3
EASTERN BASIN	3.7	6.0	7.1	7.4	7.5	8.3	8.7	9.0
TOTAL	3.1	5.5	8.4	9.4	10.4	10.6	12.1	12.6

	1966	1967	1968	1969	1970	1972	1973	1974
WESTERN BASIN	13.5	13.6	14.3	14.9	16.2	16.2	15.5	15.7
CENTRAL BASIN	12.9	13.2	13.9	14.6	15.9	15.8	15.3	15.8
EASTERN BASIN	9.0	10.2	10.6	11.5	11.7	12.0	14.7	12.7
TOTAL	13.2	13.4	14.1	14.8	16.1	16.1	15.4	15.7

Table 2.37A

Total Fertilizers Used Per Harvested Cropland (tons/acre)

	1950	1954	1959	1964	1969
WESTERN BASIN	.069	.089	.093	.122	.148
CENTRAL BASIN	.092	.097	.118	.130	.169
EASTERN BASIN	.039	.044	.048	.044	.049
TOTAL BASIN AVERAGE	.073	.091	.099	.120	.148

Table 2.38A

Percentage of Phosphorus in Fertilizer

	1950	1955	1960	1961	1962	1963	1964	1965
WESTERN BASIN	5.6	5.9	6.3	6.3	6.3	6.5	6.5	6.5
CENTRAL BASIN	5.5	5.7	6.2	6.3	6.3	6.5	6.4	6.5
EASTERN BASIN	5.8	5.0	5.1	5.2	5.2	5.3	5.3	5.4
TOTAL	5.5	5.8	6.2	6.2	6.3	6.5	6.4	6.5

	1966	1967	1968	1969	1970	1972	1973	1974
WESTERN BASIN	6.1	6.5	6.5	6.6	6.4	6.7	6.6	6.3
CENTRAL BASIN	6.3	6.4	6.5	6.7	6.5	6.7	6.8	6.4
EASTERN BASIN	5.3	5.5	5.5	6.1	5.8	6.0	5.9	5.7
TOTAL	6.2	6.5	6.5	6.6	6.5	6.7	6.7	6.3

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HISTORICAL TRENDS IN POLLUTANT LOADINGS TO LAKE ERIE.(U)
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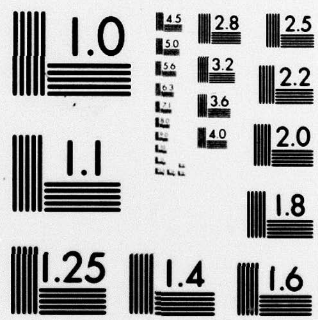

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

Table 2.41A

PER CAPITA SALES OF SOAP AND SYNTHETIC DETERGENTS - 1947-1970 (LBS./PERSON) ADJUSTED FOR THE LAKE ERIE BASIN (U.S.)

	Soap	Soap Percentage Change	Synthetic Detergents	Synthetic Detergents Percentage Change	Total	Total Percentage Change
1947	27.8		3.2		31.0	
1948	23.9	-14.0	4.9	53.1	28.8	-7.0
1949	21.9	- 8.3	6.5	32.6	28.4	-1.3
1950	21.1	- 3.6	10.6	63.0	31.7	11.6
1951	17.6	-16.5	11.2	5.8	28.8	-9.1
1952	15.5	-11.9	13.0	16.0	28.5	-1.0
1953	13.2	-14.2	14.5	11.5	27.7	-2.8
1954	11.4	-13.6	16.5	13.8	27.9	0.7
1955	10.4	- 8.8	18.3	10.9	28.6	2.5
1956	9.8	- 5.8	20.7	14.4	30.5	6.7
1957	8.9	- 9.2	21.9	5.8	30.9	1.3
1958	8.4	- 5.6	21.8	-0.5	30.2	-2.3
1959	7.5	-10.7	23.0	5.5	30.5	1.0
1960	7.2	- 4.0	23.2	0.9	30.5	0.0
1961	6.8	- 5.6	23.8	2.6	30.6	0.3
1962	6.9	1.5	25.1	5.5	32.0	4.6
1963	6.7	- 2.9	25.4	1.2	32.1	0.3
1964	6.2	- 7.5	26.0	2.4	32.3	0.6
1965	6.0	- 3.2	26.3	1.2	32.3	0.0
1966	5.9	- 1.7	26.7	1.5	32.6	0.9
1967	5.9	0.0	27.4	2.6	33.3	2.1
1968	5.8	- 1.7	27.9	1.8	33.6	0.9
1969	5.5	- 5.2	28.2	1.1	33.8	0.6
1970	5.3	- 3.6	28.8	2.1	34.1	0.9

Table 2.42A

ORGANIC SURFACTANTS PRODUCTION - 1960-72

	National Production (Mil. Lbs.)[a]	National Resident Population (Mil. People)[b]	National Per Capita Use (Lbs./Person)	Adjusted Per Capita Use (Lbs./Person)[c]	Percent Change in Adjusted Per Capita Use
1960	1532.	180.0	8.5	9.1	
1961	1729.	183.0	9.4	10.0	9.9
1962	1949.	185.8	10.5	11.1	11.0
1963	1981.	188.5	10.5	11.1	0.0
1964	2119.	191.1	11.1	11.7	5.4
1965	3170.	193.5	16.4	17.3	47.9
1966	3321.	195.6	17.0	17.9	3.5
1967	3479.	197.5	17.6	18.5	3.4
1968	3739.	199.4	18.8	19.7	6.5
1969	3901.	201.4	19.4	20.3	3.0
1970	3886.	203.8	19.1	19.9	-1.2
1971	3828	206.2	18.6	19.4	-2.5
1972	4039.	208.2	19.4	20.2	4.1

a Predicasts' Basebook, 1972, Cleveland Predicasts' Inc., Cleveland, Ohio, 1972, p. 182.

b Predicasts' Basebook, 1972, p. 1.

c Adjusted for income distribution in the Lake Erie Basin

Development of Income Correction Coefficients

The first step in calculating these coefficients was to determine the ratio of the average per capita income for the state to that of the entire United States. Next the income ratio of each state was weighed by the fraction of population living in the Lake Erie Basin. Finally, the values for 1950, 1960 and 1970 were plotted and interpolated to obtain values for the desired years.

Average incomes and basin populations are given by states as follows:

	1950	1960	1970
PER CAPITA INCOME: (69)			
U.S.	$1,501	$2,219	$3,945
N.Y.	1,873	2,742	4,714
Pa.	1,541	2,247	3,943
Ohio	1,620	2,338	3,992
Mich.	1,701	2,338	4,156

	1950	1960	1970
POPULATION IN LAKE ERIE BASIN:			
N.Y.	512,931	599,790	619,507
Pa.	200,396	229,512	235,998
Ohio	2,872,861	3,951,746	4,259,248
Mich.	3,607,366	4,470,621	4,996,819

Step 1: Ratio of State Per Capita Income to U.S. Per Capita Income

	1950	1960	1970
N.Y.	1.248	1.236	1.195
Pa.	1.027	1.013	0.999
Ohio	1.079	1.054	1.012
Mich.	1.133	1.054	1.054

Step 2: Weighing by population

k_{50} (coefficient for 1950) =

$[(1.248)\ (512{,}931) + (1.027)\ (200{,}396)$

$+ (1.079)\ (2{,}872{,}861) + (1.133)\ (3{,}607{,}366)]$

$/(512{,}931 + 200{,}396 + 2{,}872{,}861 + 3{,}607{,}366)$

$= 1.117$

Similarly,

$k_{60} = 1.165$

$k_{70} = 1.044$

Step 3: Plot coefficient values and interpolate for years 1947 to 1972.

This is shown in Figure 2.32

The final coefficients are:

1947 - 1.140	1960 - 1.065
1948 - 1.132	1961 - 1.063
1949 - 1.124	1962 - 1.060
1950 - 1.117	1963 - 1.058
1951 - 1.111	1964 - 1.055
1952 - 1.104	1965 - 1.053
1953 - 1.098	1966 - 1.051
1954 - 1.093	1967 - 1.049
1955 - 1.087	1968 - 1.047
1956 - 1.082	1969 - 1.045
1957 - 1.078	1970 - 1.044
1958 - 1.073	1971 - 1.042
1959 - 1.069	1972 - 1.041